3.0 ANNUAL SUSPENDED-SEDIMENT LOADS AND YIELDS

3.1 Introduction

Annualized data on suspended-sediment loads and yields (load per unit area) are a convenient means of interpreting sediment production and delivery. With regard to sediment delivery to Lake Tahoe, data expressed as annual loads (in T/y) provide a means of differentiating those watersheds that are particularly critical in terms of gross amounts of sediment delivered on an annual basis. This is of course essential in interpreting issues involving lake clarity. With other things being equal, however, larger watersheds will generally provide greater suspended-sediment loads than smaller watersheds, but this tells us little about differences in sediment production and delivery processes between watersheds. Suspended-sediment yields, expressed in $T/y/km^2$ do provide a mechanism to interpret differences in sediment production and delivery because they describe loads per unit of drainage area. Because suspended-sediment yields will vary with time as runoff conditions change, temporal trends of annualized data are also expressed as an annual concentration (load per unit of runoff; in g/m^3) to (1) interpret differences in sediment production and sources within watersheds and, (2) determine temporal trends over the past 40 years.

3.2 Availability and Reliability of Data

Annual suspended-sediment loads and yields are calculated for 32 sites using historical mean-daily flow data and sediment-transport rating relations. The length of record, depending on the number of complete calendar years of flow data, ranged from two to 40 years with a mean of 12 years (Table 3-1). Eleven sites had four years or fewer of mean-daily flow data. Most of these stations were sampled in the early 1970's (1970-1974) by the U.S. Geological Survey (Kroll, 1976; Glancy, 1988). Fortunately, the flow recorded over this period is reasonably representative of longer periods of record. Average, mean-daily flows for the period are only 3 – 5% less than those for the full period of record on Incline and Third Creeks. Annual peak flows on Third Creek are just 9% higher during this short period in the 1970s. Similar patterns are seen on the west side of the lake where a number of gages were operated only during the early 1970s.

First approximation rating relations are derived from linear regression of instantaneous flow and suspended-sediment concentration data plotted in log-log space. As is often the case, this single power curve is inadequate to describe the relation between discharge and sediment load over the entire range of flows. In these cases two- or three-linear segments (in log-log space) are used. The break point for each segment is determined by eye. An example is shown in Figure 2-6. Plots of all rating relations are shown in Appendix C. Where applicable and where sufficient data are available, rating relations are also calculated for transport conditions prior to, and after the January 1-2, 1997 rain on snow runoff event. Finally, the resulting power functions are all closely inspected to make sure that the maximum mean-daily flow that is used to calculate daily loads does not exceed the maximum sampled flow rate. This is particularly critical at high flow rates where a small increment in discharge can result in large errors in the calculated sediment load.

Suspended-sediment loads for each complete calendar year of flow data were calculated by applying the appropriate transport rating to the mean-daily flow for that day. Flow rates based on 15-minute gage readings would have been superior, however, most of the 15-minute gage record contains varying periods of missing data, making it impossible to obtain annual values.

It is important to keep in mind that for a given station, discharge and suspended-sediment loads may range over four to six orders of magnitude. Data scatter around a suspended-sediment transport rating with an r^2 value as high as 0.9 still has only order of magnitude accuracy in predicting loads at a given discharge. Thus, suspended-sediment loadings are not actually measured, but calculated from measured flow and concentration data. In general, caution should be exercised in using 95% prediction limits around rating relations and not 95% confidence limits. The difference is that the confidence limits reflect the reliability of the relation to describe the trend in load with discharge whereas prediction limits refer to the reliability of estimating suspended-sediment loads at a given discharge.

3.3 Basin Quadrants and Index Stations

Precipitation and other basin characteristics vary from one side of the lake to the other resulting in a broad range of sediment-transport rates. To partially account for these differences and to make interpretations of differences in suspended-sediment loads and yields to Lake Tahoe, watersheds are separated into the four principle directional quadrants; north, south, east, and west (Figure 3-1). Streams referred to as “northern” include First, Second, Third, and Incline Creeks. The major “southern” streams are the Upper Truckee River and Trout Creek. “Eastern” streams include Edgewood, Glenbrook and Logan House Creeks, while “western” streams include Blackwood, Ward, and General Creeks.

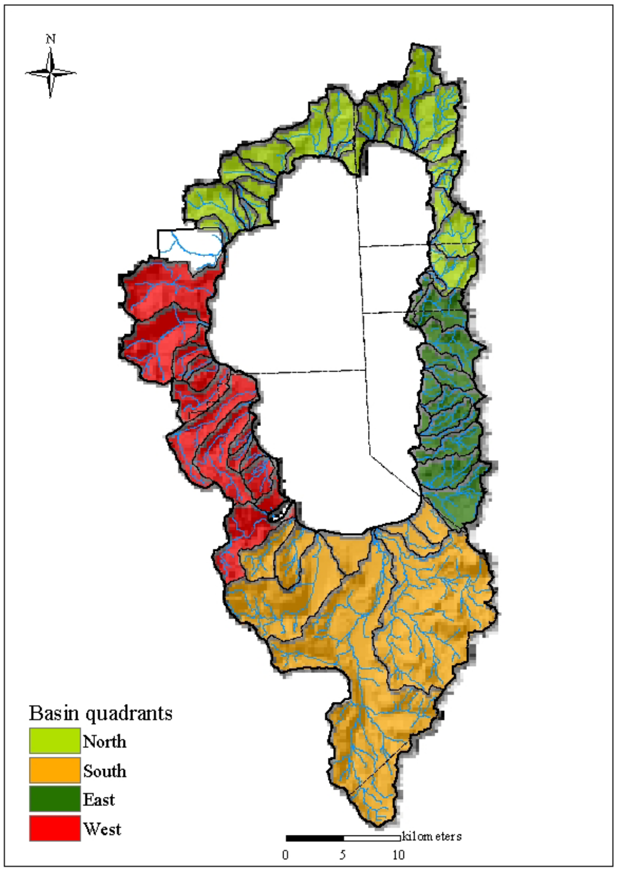


Figure 3-1. Map of Lake Tahoe watershed showing designation of the four basin quadrants.

Index stations were selected from the 32 sampling stations (Table 3-1). The concept of an index station is that sediment loadings and yields from a particular watershed to Lake Tahoe can be represented by sediment-transport data from a specific downstream location in the watershed. Selection of these stations are based on two criteria; (1) the station from a given stream with the longest period of record and, (2) the station has a downstream location. These stations are then used to interpret similarities and differences in sediment delivery to the lake.

Table 3-1. List of index stations used to differentiate suspended-sediment loads and yields to Lake Tahoe from individual watersheds.

Stream	Station number	Basin quadrant	Distance above mouth (km)	Period of record (y)
First	10336688	N	0.13	4
Second	10336691	N	0.52	4
Third	10336698	N	0.19	26
Incline	10336700	N	0.27	17
Wood	10336692	N	0.02	4
Trout	10336780	S	4.52	40
Upper Truckee	10336610	S	2.94	24

Edgewood	103367585	E	3.81	11
Glenbrook	10336730	E	0.04	16
Logan House	10336740	E	0.66	17
Eagle Rock	103367592	E	2.99	10
Blackwood	10336660	W	0.31	40
General	10336645	W	0.65	20
Meeks	10336640	W	0.45	3
Ward	10336676	W	0.44	28
Quail Lake	10336650	W	0.07	3
Eagle	10336630	W	0.57	3

3.4 Total Annual Suspended-Sediment Loads

Annual suspended-sediment loads generally vary over about four orders of magnitude with time at a particular station, and from watershed to watershed. This variability can simply reflect differences in drainage area or, be a function of differences in precipitation, and basin and channel characteristics. Median annual suspended-sediment loads range from about 0.5 T/y on Logan House Creek (10336740) to about 2,200 T/y on the Upper Truckee River (10336610) (Table 3-2). Median values are used for comparison purposes in lieu of means because of the overriding influence of the large runoff events. To compare downstream loadings from individual watersheds, the median-annual loads for the 18 index stations are highlighted in green in Table 3-2. The greatest annual loads, in decreasing order emanate from the Upper Truckee River (2200 T/y), Blackwood (1930 T/y), Second (1410 T/y), Trout (1190 T/y), Third (880 T/y), and Ward Creeks (855 T/y). The lowest annual loads, in increasing order emanate from Logan House (0.5 T/y), Eagle Rock (4.6 T/y), Dollar (4.6 T/y), Quail Lake (6.4 T/y), Glenbrook (8.9 T/y), and Edgewood Creeks (21.3 (T/y).

Table 3-2. Summary of total annual suspended-sediment loads calculated from measured data. Sites shaded in green are index stations.

Stream	Station number	Annual load		Quadrant	Complete years of data	Drainage area (km^2)
		Average (tonnes)	Median (tonnes)			
Upper Truckee	10336610	2850	2200	S	24	142
Blackwood	10336660	3060	1930	W	40	29.0
Upper Truckee	103366092	1410	1410	S	10	88.8
Second[2]	10336691	1500	1410	N	4	4.7
Trout	10336780	1790	1190	S	40	95.1
Third	10336698	1680	880	N	26	15.7
Ward	10336676	1730	855	W	28	25.1
Ward	10336670	641	638	W	3	5.2
Wood[2]	10336692	467	490	N	4	5.3
Ward	10336675	551	449	W	9	23.2
First[2]	10336688	402	413	N	4	2.8
Ward	10336674	427	356	W	9	12.9
Trout	10336790	360	355	S	5	105

Upper Truckee	10336580	363	334	S	10	36.5
Trout	10336775	376	331	S	10	61.4
Incline	10336700	612	217	N	17	18.1
Grass[1]	10336593	181	181	S	3	16.6
General	10336645	283	176	W	20	19.3
Incline	103366995	174	163	N	11	11.6
Trout	10336770	158	109	S	10	19.1
Incline	103366993	80.1	90.5	N	10	7.2
Meeks[1]	10336640	79.8	79.8	W	3	22.2
Eagle[1]	10336630	69.9	69.9	W	3	20.4
Edgewood	10336760	34.7	44.8	E	8	14.2
Edgewood	103367585	24.5	21.3	E	11	8.1
Edgewood	10336765	9.5	9.5	E	2	16.2
Glenbrook	10336730	11.3	8.9	E	16	10.5
Quail Lake[1]	10336650	6.4	6.4	W	3	4.2
Dollar[1]	10336684	4.6	4.6	N	3	4.7
Eagle Rock	103367592	5.6	4.6	E	10	1.5
Logan House	10336740	5.6	3.0	E	17	5.4
Edgewood Trib.	10336756	0.5	0.5	E	2	0.6

[1] = Mean values from Kroll (1976)
[2] = Data from Glancy (1988)

The spatial distribution of mean annual suspended-sediment loads (in T/y) are shown broken into five classes and mapped in Figure 3-2 with the darker colors indicating higher suspended-sediment loads. Note that the index stations on Blackwood Creek (10336660) and the Upper Truckee River (10336610) show the greatest values while the eastern streams in general have the lowest. The latter is in part due to the smaller watershed areas on the east side of the lake as well as lower runoff rates. Whereas high loadings rates are expected from large watersheds such as Trout Creek and the Upper Truckee River, the index stations on Blackwood, Ward (10336676) and Third Creeks (10336698) show relatively high loadings for their drainage area, indicating past and or present disturbances and the potential for high rates of channel erosion.

To compare loadings from sampled watersheds, data from Table 3-2 is perhaps better displayed graphically as in Figure 3-3 where median annual suspended-sediment loads are shown in descending order for the 18 index stations (Figure 3-3a) and by basin quadrant (Figure 3-3b). One of the most striking aspects of Figure 3-3b are the exceptionally low loadings rates for the eastern streams including those that have experienced significant urbanization, such as Edgewood Creek, and on Glenbrook Creek where construction of roads and road cuts has been listed as a cause of heightened loads (Kroll, 1976). Median annual water yields for the three main index stations in the east (Glenbrook, Edgewood, and Logan House Creeks) range from 0.09 m^3/m^2 to 0.20 m^3/m^2 for Logan House and Edgewood Creeks, respectively. In contrast, median annual water yields from the three main western index stations range from 0.80 m^3/m^2 to 1.17 m^3/m^2 for General and Ward Creeks, respectively. Still, because of greatly different rates of runoff in comparison with the larger and wetter western streams, suspended-sediment loads from disturbed watersheds in the eastern quadrant do not approach those from the western quadrant.

It is the relatively high water yields of the western streams that make them particularly sensitive to disturbance. Note the vastly greater suspended-sediment loads produced from the Blackwood and Ward Creek watersheds in comparison to the relatively undisturbed General, Meeks, and Eagle Creek watersheds.

Streams draining the northern quadrant of the Lake Tahoe Watershed have relatively high loads of suspended-sediment. This is one of the most intensely developed parts of the basin. Data for streams such as First, Second and Wood Creeks are only from the early 1970's and although they reflect representative flows, the period comes at the end of a decade of intense development that continued into the sampling period. Glancy (1988) lists 34 development projects in the Incline Village area between 1960 and 1970, and refers to this as a period of "dynamic non-equilibrium" for the streams draining to Crystal Bay. Both Third and Second Creeks also experienced thunderstorm-induced flash floods in 1965 and 1967 respectively that caused large changes in channel characteristics (Glancy, 1988). As such, suspended-sediment loads (per unit amount of water) should be at their highest during this period and attenuate with time (Simon, 1992). Thus, care should be used in interpreting long-term suspended-sediment transport for the northern streams based on data collected only in the early 1970's.

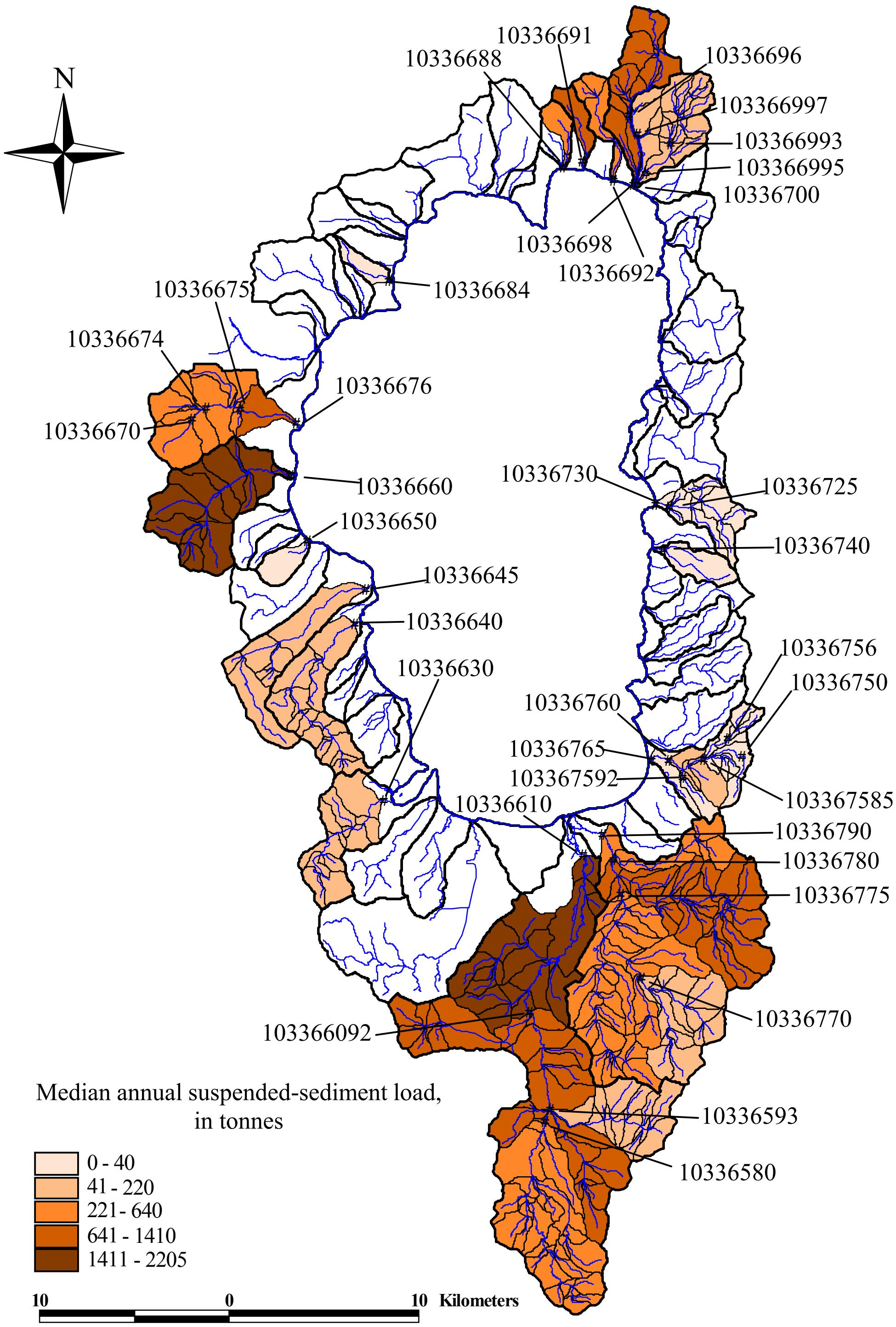


Figure 3-2. Distribution of median annual suspended-sediment loads in tonnes.

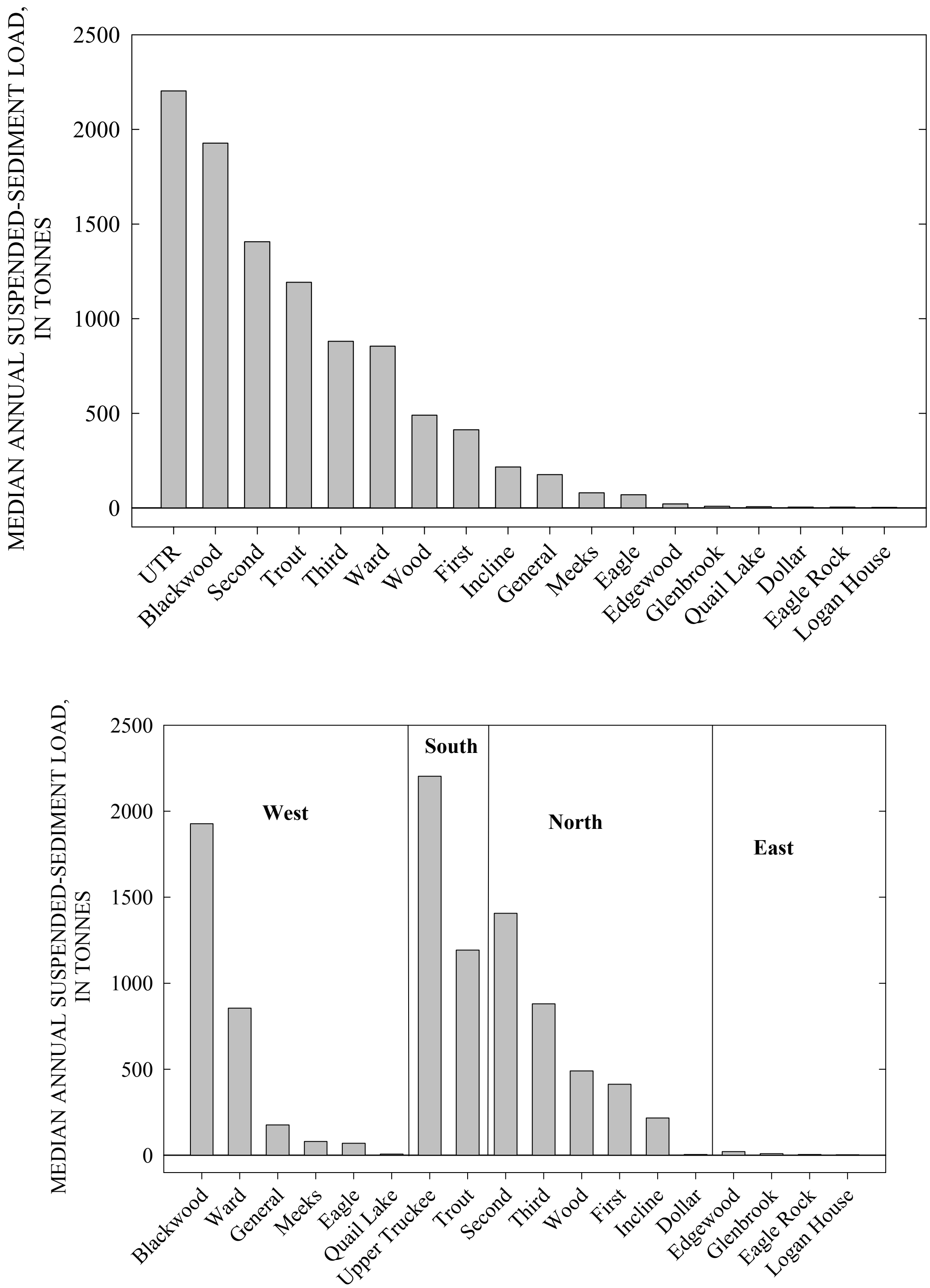


Figure 3-3. Median annual suspended-sediment loads for the 18 index stations sorted in descending order (upper) and, separated by basin quadrant (lower).

Interpretations of the cause of differences in sediment loadings between quadrants, and between watersheds within a given basin quadrant are better expressed in terms of suspended-sediment yields (in T/y/km^2). Still, Figure 3-3 and Table 3-2 provide annual estimates of absolute values and differences in total suspended-sediment loads from most of the largest watersheds draining to Lake Tahoe.

3.4.1 Comparisons with Previously Published Data

Suspended-sediment loads to Lake Tahoe have been the topic of numerous technical publications over the past 30 years (Glancy, 1969; 1988; Kroll, 1976; Leonard, *et al*., 1979; Hill *et al*., 1990; Hill and Nolan, 1990; Nolan and Hill, 1991; Reuter and Miller, 2000; Rowe *et al*., 2002). Results from some of these reports have been used herein (Kroll, 1976 and Glancy, 1988) to enhance geographic coverage of the annual load data. Annual suspended-sediment loads calculated in this study are compared with previously published values in Table 3-3. Data from a recent report by Rowe *et al*., (2002) are not comparable because they are expressed as median monthly values. Simply multiplying by 12 does not produce a reliable annual value because of the uncertainty in the distribution of monthly values.

Given the great temporal and spatial variability in suspended-sediment loads, it is encouraging that data from Kroll (1976), Nolan and Hill (1991), Reuter and Miller (2000) and this study are generally within an order of magnitude. Differences in annual load calculations between the studies does not indicate numerical or methodological errors but are probably related to different periods of record. The current study is at somewhat of an advantage because it has access to longer periods of flow and sediment concentration record. For instance, that Reuter and Miller's (2000) annual load estimates from Incline and Trout Creeks are well below those calculated in this study is probably due to the fact that high sediment-producing years of 1970 and 1971 in the case of the former, and 1967, 1969, 1982, 1983, 1986, and 1997 in the case of the latter, are not included in their data set.

Table 3-3. Comparison of published, average annual suspended-sediment loads unless labeled otherwise. All data expressed in tonnes per year.

Stream	Data from Reuter and Miller, 2000[1]	Data from Nolan and Hill, 1991[2]	Data from Kroll, 1976[3]	This study (averages)	This study (medians)
Blackwood	2090	2030	-	3060	1930
Edgewood	-	40.3	-	24.5	21.3
General	201	201	-	283	176
Glenbrook	31.9	-	-	11.3	8.9
Incline	107[4]	-	-	612	217
Logan House	5.7	3.8	-	5.6	3.0
Trout	798	-	1540	1790	1190
Upper Truckee	3310	-	3900	2850	2200
Ward	899	-		1730	855

[1] Data for water years 1989-1996.

[2] Data for water years 1984-1987.
[3] Data for water years 1972-1974
[4] Revised from J. Reuter (per. commun., 2003).

3.4.2 Timing of Peak Annual Suspended-Sediment Loads

Total annual suspended-sediment loads vary greatly from year to year at a given station across the Lake Tahoe Basin in response to annual variability in rates of runoff and human intervention, making interpretations of temporal trends a complex issue. Years of peak loading rates are not consistent across the basin and again reflect differences in how precipitation-runoff relations vary between basin quadrants. Using the past 40 years as an example, western streams displayed peak loads for their period of record in 1997 in response to the rain on snow event in January of that year (Figure 3-4). In contrast, streams draining the southern part of the Lake Tahoe watershed experienced peak suspended-sediment loads in 1983. Although the northern and eastern streams have shorter periods of record, the dates of peak annual suspended-sediment loads in these quadrants were 1995 and 1996, respectively (Figure 3-4). The scale of temporal variability displayed in Figure 3-4 provides a clear justification for maintaining streamflow and sediment data collection operations for long periods of time. The important question as to whether the delivery of suspended sediment to Lake Tahoe, particularly material finer than .062 mm is changing with time will be treated in a later section of this chapter.

3.4.3 Suspended-Sediment Loads From The January 1-2, 1997 Runoff Event

A New Year's Day rainstorm in 1997 created super-saturated snow packs and resulted in large runoff events throughout the Lake Tahoe Basin. As discussed in the previous section, suspended-sediment loads resulting from this event were very high, representing the peak of record in some watersheds. To address just how large this event was in terms of sediment loads, and how frequently one could expect loads of this magnitude again, peak values were used to determine the recurrence interval of the sediment-transporting event across the basin. The recurrence interval of the instantaneous peak discharge ranged from about 56 years at the index station on the Upper Truckee River (10336610) to about 2.4 years for an upstream station on nearby Trout Creek (10336770) (Table 3-4). Runoff magnitudes for the western index stations ranged from 23 years on General Creek to 35 years on Ward Creek. It is interesting to note that there are considerable differences within basin quadrants. For example, upstream sites on Incline Creek and the index station on Third Creek had relatively low return periods of 6 to 13 years while the index station on Incline Creek (10336700) experienced a calculated 50-year event. In terms of sediment production, however, a different picture emerges.

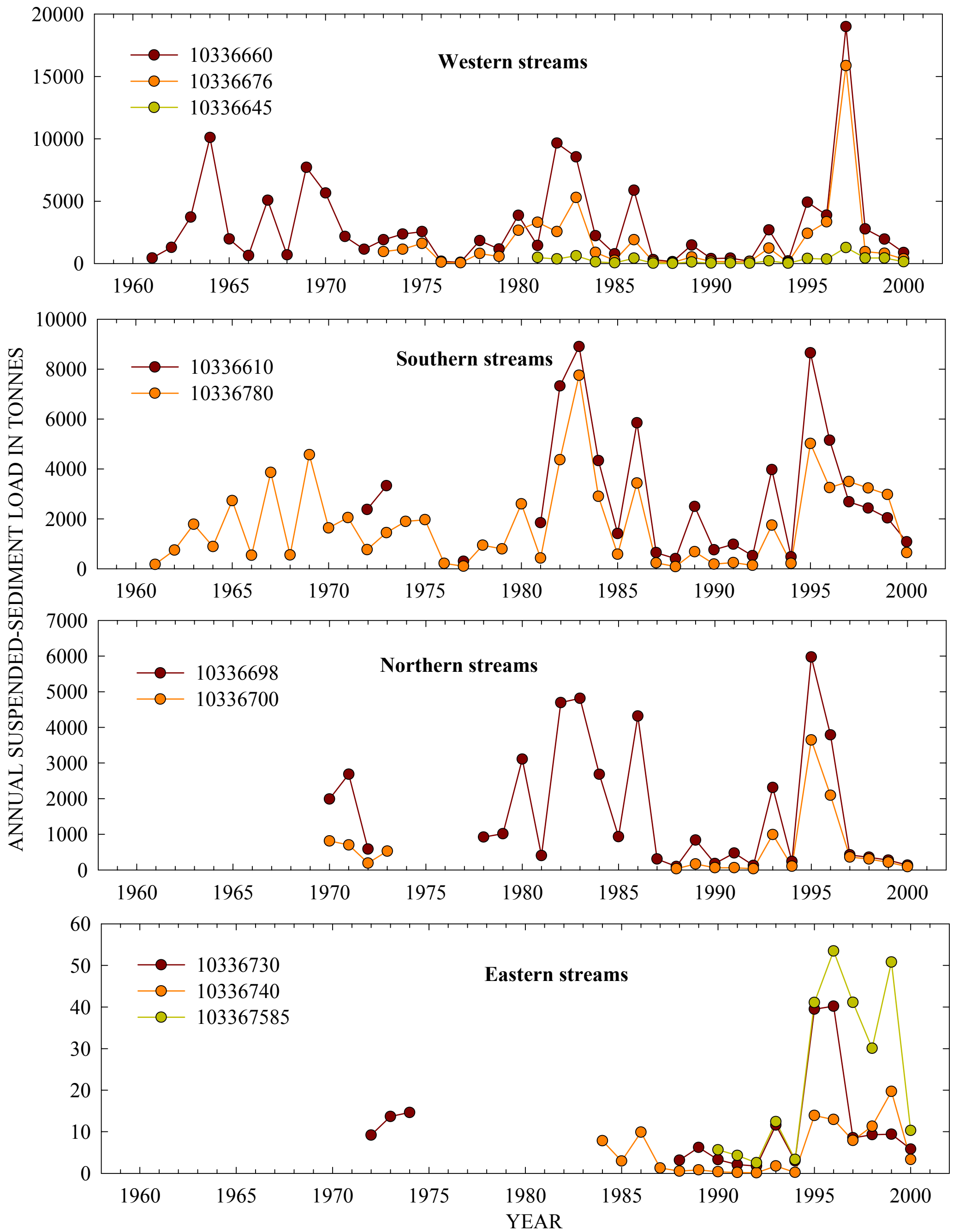


Figure 3-4. Temporal variability in total annual suspended-sediment loads for ten selected index stations in the four basin quadrants.

Table 3-4. Maximum-daily and instantaneous peak discharge for the January 1-2, 1997 runoff event ranked by recurrence interval.

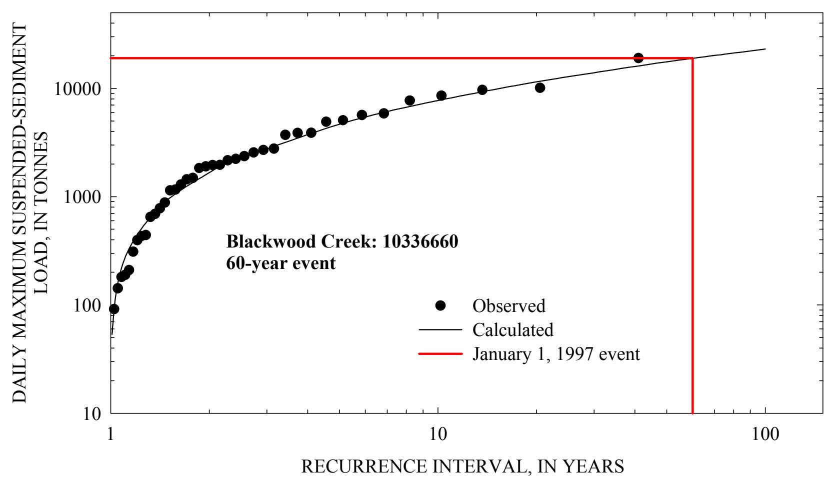
Stream	Station	Quadrant	Max Daily Flow (m^3/s)	Instantaneous Peak (m^3/s)	Recurrence Interval (y)	Flow rank
UTR	10336610	S	89.2	155	55.9	1
Incline	10336700	N	3.17	5.07	49.9	2
Glenbrook	10336730	E	2.41	4.08	37.7	3
Ward	10336676	W	39.4	71.6	35.0	4
Blackwood	10336660	W	56.6	83.2	32.7	5
UTR	10336580	S	32.0	56.9	30.8	6
General	10336645	W	17.0	22.6	23.4	7
Eagle Rock	103367592	E	0.10	0.11	22.9	8
Trout	10336780	S	14.2	15.1	21.2	9
UTR	103366092	S	56.6	145	20.6	10
Ward	10336674	W	20.4	34.5	16.9	11
Ward	10336675	W	36.8	67.1	16.4	12
Edgewood	10336760	E	2.89	3.85	15.0	13
Trout	10336775	S	12.9	14.9	14.9	14
Incline	103366995	N	2.41	4.05	12.9	15
Logan House	10336740	E	0.25	0.34	11.1	16
Edgewood	103367585	E	1.05	1.44	9.7	17
Incline	103366993	N	1.02	1.47	6.5	18
Third	10336698	N	2.27	3.06	5.9	19
Trout	10336770	S	2.27	2.66	2.4	20

Table 3-5. Maximum-daily loads for the January 1-2, 1997 runoff event ranked by recurrence interval.

Stream	Station	Quadrant	Max Daily Load (T/d)	Flow rank	Sediment recurrence interval (y)	Sediment rank
Blackwood	10336660	W	8950	5	60	1
Ward	10336676	W	7840	4	52	2
General	10336645	W	938	7	40	3
Ward	10336674	W	543	11	25	4
Trout	10336780	S	321	9	24	5
UTR	10336580	S	292	6	24	6
Edgewood	103367585	E	13.8	17	21	7
Edgewood	10336760	E	7.0	13	21	8

Glenbrook	10336730	E	1.1	3	17	9
Incline	103366995	N	22.9	15	14	10
UTR	103366092	S	565	10	14	11
Incline	103366993	N	11.5	18	13	12
Logan House	10336740	E	1.6	16	13	13
Trout	10336775	S	58.4	14	12	14
Ward	10336675	W	229	12	8	15
UTR	10336610	S	314	1	8	16
Eagle Rock	103367592	E	0.06	8	7	17
Incline	10336700	N	31.7	2	6	18
Trout	10336770	S	3.4	20	2.4	19
Third	10336698	N	20.0	19	1.4	20

Peak suspended-sediment loads expressed in terms of recurrence interval are dominated by the western streams with index stations registering return periods ranging from 40 to 60 years. In fact, four of the highest return periods were from stations in the western quadrant (Table 3-5). A comparison of how the January 1997 event represented widely varying frequencies of occurrence is shown in Figure 3-5 showing all of the annual, maximum-daily peak suspended-sediment loads for two index stations. For streams draining the eastern quadrant the magnitude of the sediment-transporting event was intermediate with return periods for index stations ranging from 13 to 21 years (Table 3-5).



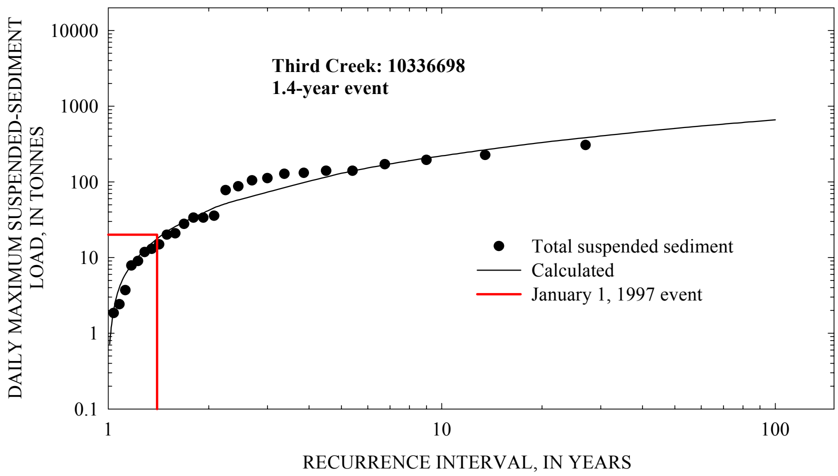


Figure 3-5. Magnitude-frequency analysis of annual, maximum-daily suspended-sediment loads for index stations on Blackwood Creek (10336660) and Incline Creek (10336700), showing widely varying return periods for the January 1, 1997 event.

3.4.4 Effect of January 1997 Runoff Event on Suspended-Sediment Transport Rates

With the relative magnitudes of flows and suspended-sediment loads resulting from the January 1997 runoff event varying widely across the Lake Tahoe Basin, analyses were conducted to determine what affects, if any, these had on future sediment transport rates. To accomplish this, mean-daily sediment loads for each station were separated into periods representing pre- and post-1997 data sets and regressed with mean-daily discharge to produce suspended-sediment transport rating relations before and after the runoff event.

Visual inspection of the plotted ratings showed generally lower sediment loads for a given discharge across the range of discharges for most stations. This indicates that the January 1997 event flushed stored sediment from the stream channels leaving less available for subsequent transport (Figure 3-6). However, given the amount of data scatter it was difficult in some cases to determine whether these differences were real and significant.

Using a combination of sum of squares (SS) statistical tests applied to the pre- and post-1997 rating relations, we evaluated whether the paired regressions are significantly different from one another. Only Second Creek (10336691), and Incline Creek (10336697) showed no discernable change. The Type I SS tests whether the slope of the rating is different than 0.0. The Type III SS tests whether the slopes or intercepts of the ratings are significantly different. Initial results showed that in most cases the SS tests indicated that either the slopes and/or intercepts of the paired regressions were significantly different at the 0.05 level. Still, these results were not convincing in that the statistics pertain to the confidence limits of the regression and not prediction limits. For example, SS results for pre- and post-1997 ratings for Blackwood Creek (Figure 3-6) indicate a statistically significant decrease in loads after January 1997 but inspection of the plot leaves this conclusion in doubt. To alleviate this problem we set stricter limits on the Type III SS measure (P-value) to 0.0001 and the ratio of explained to unexplained variance (F-value) to about 20 to discriminate those sites having significant sediment flushing after January

1997. Those stations determined to have lower transport rates across the range of discharges post January 1997 are shown in Table 3-6.

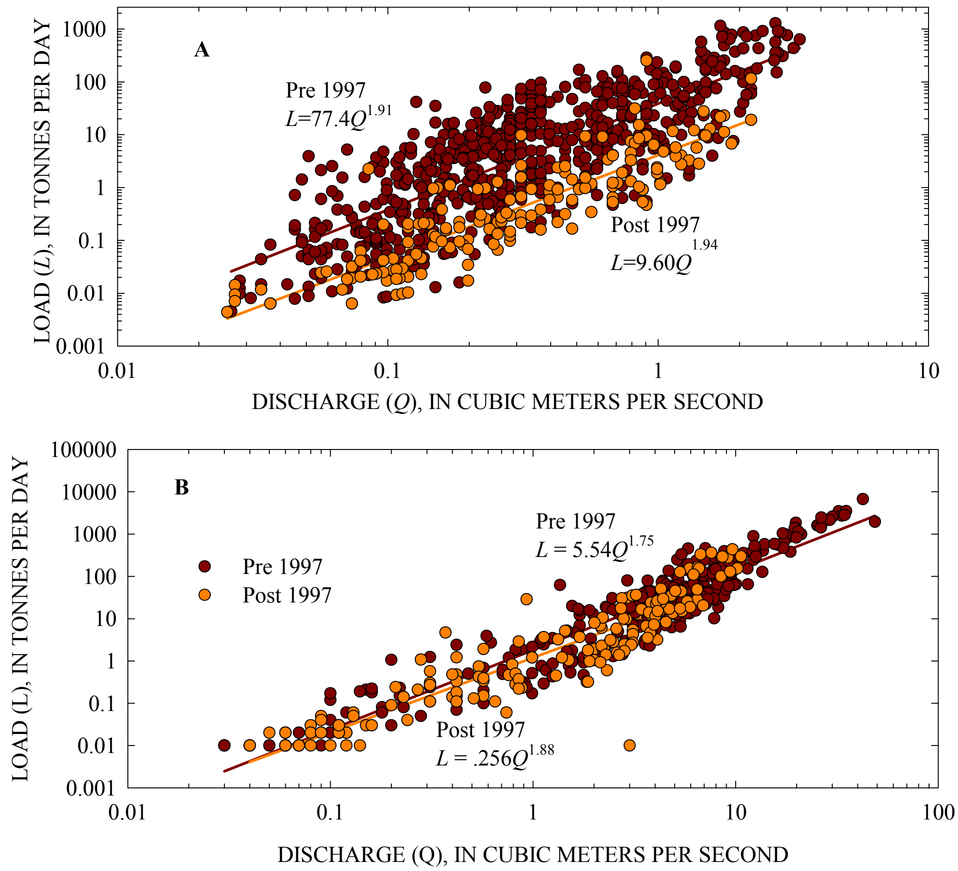


Figure 3-6. Examples of pre- and post-1997 suspended-sediment transport ratings for index station on Third Creek (10336698) showing flushing effect of January 1997 runoff event (A), and for Blackwood Creek (10336660) showing no discernable affect.

Table 3-6. Summary of significant statistical relations indicating decreasing suspended-sediment loads across the range of discharges following the January 1-2, 1997 runoff event.

Stream	Station	Quadrant	F- value	P-value	Post 1997 trend
UTR	10336610	S	24.1	<.0001	decreasing
Trout	10336790	S	27.7	<.0001	decreasing
Trout	10336775	S	26.5	<.0001	decreasing
Trout	10336770	S	34.0	<.0001	decreasing
Ward	10336676	W	38.1	<.0001	decreasing
Incline	10336700	N	136	<.0001	decreasing
Incline	10336693	N	45.9	<.0001	decreasing
Incline	10336695	N	50.8	<.0001	decreasing
Third	10336698	N	272	<.0001	decreasing
Third	10336695	N	28.6	<.0001	decreasing

Third	103366958	N	27.5	<.0001	decreasing
Wood	10336692	N	27.3	<.0001	decreasing
Wood	10336694	N	63.6	<.0001	decreasing
First	10336688	N	47.1	<.0001	decreasing
Logan House	10336740	E	20.3	<.0001	decreasing
Edgewood	103367585	E	47.4	<.0001	decreasing
Edgewood	10336765	E	24.9	<.0001	decreasing

3.5 Total Annual Suspended-Sediment Yields

Interpreting suspended-sediment transport rates as yields per unit of drainage area (in T/km^2) is a convenient way to discern differences in sediment production and delivery from different watersheds and from different sites within watersheds. Table 3-7 lists in descending order the median values of total annual suspended-sediment yields for all sites with historical data. As with Table 3-2, the 18 index stations are highlighted in green. Of the four highest yield values shown in Table 3-7, three are from the northern quadrant and were sampled only in the early 1970's, representing the dis-equilibrated conditions of that period and do not represent long-term conditions. The fourth, from Ward Creek also represents a very short period of record although it drains an erosive headwaters area of the basin. Notwithstanding these potential biases, the greatest median suspended-sediment yields emanate from Blackwood (66.4 $T/y/km^2$), Third (56.2 $T/y/km^2$), Ward (34.1 $T/y/km^2$), Upper Truckee (15.5 $T/y/km^2$), and Trout (12.5 $T/y/km^2$). The lowest yields in ascending order are Logan House (0.6 $T/y/km^2$), Glenbrook (0.8 $T/y/km^2$), Dollar (1.0 $T/y/km^2$), Quail Lake (1.5 $T/y/km^2$), and Edgewood (2.6 $T/y/km^2$). Note that most of these low-yielding index streams are located in the eastern quadrant of the basin.

Table 3-7. Total annual suspended-sediment yields. Stations shaded in green are index stations.

Stream	Station number	Annual Yield		Quadrant	Years of data	Drainage area (km^2)
		Average (tonnes/km^2)	Median (tonnes/km^2)			
Second[2]	10336691	319	300	N	4	4.7
First[2]	10336688	142.0	146	N	4	2.8
Ward	10336670	128	128	W	3	5.2
Wood[2]	10336692	89	93	N	4	5.3
Blackwood	10336660	105	66.4	W	40	29.0
Third	10336698	107	56.2	N	26	15.7
Ward	10336676	68.9	34.1	W	28	25.1
Ward	10336674	33.2	27.7	W	9	12.9
Ward	10336675	23.7	19.5	W	9	23.2
UTR	103366092	15.9	15.9	S	10	88.8
UTR	10336610	20.1	15.5	S	24	142
Incline	103366995	15.1	14.1	N	11	11.6
Incline	103366993	11.1	12.6	N	10	7.2
Trout	10336780	18.9	12.5	S	40	95.1
Incline	10336700	33.8	12.0	N	17	18.1
Grass[1]	10336593	10.9	10.9	S	3	16.6
UTR	10336580	10.0	9.2	S	10	36.5
General	10336645	14.7	9.1	W	20	19.3
Trout	10336770	8.2	5.7	S	10	19.1
Trout	10336775	6.1	5.4	S	10	61.4
Meeks[1]	10336640	3.6	3.6	W	3	22.2
Eagle[1]	10336630	3.4	3.4	W	3	20.4
Trout	10336790	3.4	3.4	S	5	105
Edgewood	10336760	2.4	3.2	E	8	14.2
Eagle Rock	103367592	3.6	3.0	E	10	1.5
Edgewood	103367585	3	2.6	E	11	8.1
Quail Lake[1]	10336650	1.5	1.5	W	3	4.2
Dollar[1]	10336684	1.0	1.0	N	3	4.7
Edgewood Trib.	10336756	0.9	0.9	E	2	0.6
Glenbrook	10336730	1.1	0.8	E	16	10.5
Logan House	10336740	1.0	0.6	E	17	5.4
Edgewood	10336765	0.6	0.6	E	2	16.2

1 = Data from Kroll (1976)
2 = Data from Glancy (1988)

The spatial distribution of annual suspended-sediment yields are somewhat similar to the loads distribution but with some important differences (Figure 3-7). Both of the disturbed western streams (Blackwood and Ward Creeks) are in the highest sediment producing class, reflecting the critical nature of human intervention on this side of the lake. In contrast, the relatively undisturbed General Creek has a median annual yield value of 9.1 T/y/km^2, thus providing a measure of the magnitude of the disturbances on Blackwood and Ward Creeks. The Upper Truckee River and Trout Creek although being among the largest contributors of suspended sediment to Lake Tahoe display only moderate suspended-sediment yields (15.5 and 12.5 T/y/km^2, respectively). This reinforces the notion that it is the sheer size of these watersheds relative to other basins in the Lake Tahoe watershed that is an important factor in the magnitude of their sediment contributions to the lake. This is not to say, however, that human intervention and other factors in the flatter alluvial sections of these streams has not led to accelerated bank erosion and suspended-sediment transport rates, but that yields from these two watersheds are not exceptional.

Eastern streams again generally display the lowest suspended-sediment transport values in the Lake Tahoe watershed (Figures 3-2, 3-3, and 3-7; Table 3-7); a direct function of low runoff rates and water yields. Median annual suspended-sediment yield from the index station located in the developed (disturbed) Edgewood Creek watershed are still relatively low (2.6 T/y/km^2).

When sorted by basin quadrant (Figure 3-8a), suspended-sediment yields for the 18 index stations appear to be dominated by the northern quadrant streams Second (300 T/y/km^2), First (146 T/y/km^2), and Wood Creeks (93 T/y/km^2). Because of a sampling period that coincided with rapid development and instability in these basins, values reported here are probably not representative of long-term averages for developed streams in this quadrant. Removing these three sites from the plot provides a more accurate picture of median suspended-sediment yields across the four basin quadrants (Figure 3-8b). However, comparing values from the eastern quadrant streams in Figures 3-8a and 3-8b does provide a means of comparing sediment production during development with long-term values. Yields from Third Creek, a watershed disturbed at various times over the 26-year sampling period by re-routing of channels, urbanization, and road construction has a high median suspended-sediment yield (56.2 T/y/km^2). This value is still 2 to 6 times less than median values between 1970 and 1974. Over the period of record, Third Creek produces as much sediment per unit area as unstable streams on the western side of the lake even though median annual water yield is about half (0.46 m^3/m^2).

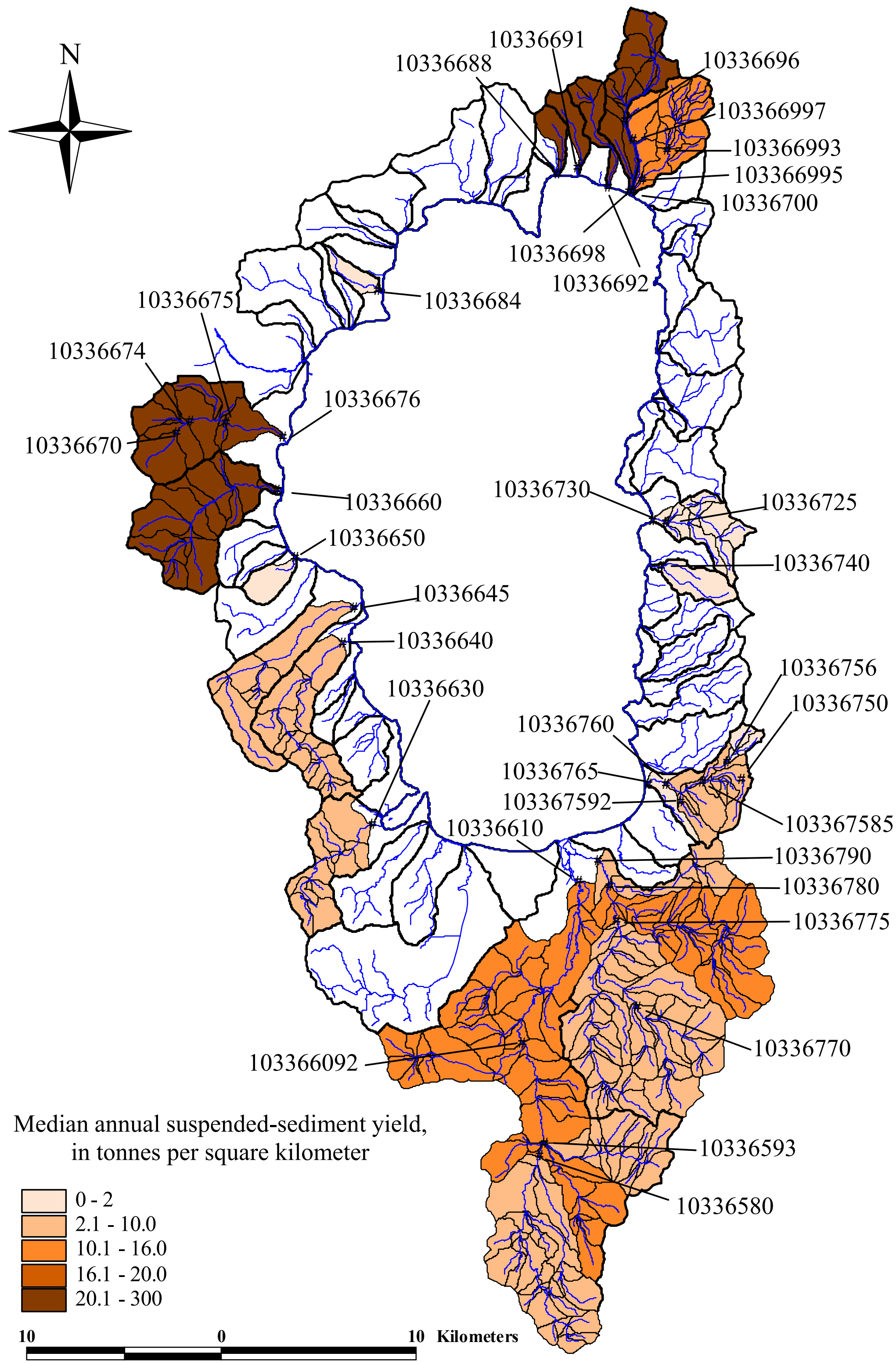


Figure 3-7. Median annual suspended-sediment yields.

It is believed that the combination of upland mass-wasting processes in the undeveloped, upstream part of the basin (Entrix, 2001), combined with erosion from cut slopes and streambanks in the downstream developed areas has resulted in the high long-term suspended-sediment yield. In comparison, the adjacent, developed Incline Creek watershed maintains considerably lower suspended-sediment yields (median = 12.0 $T/y/km^2$) even though the two basins have similar road densities (a measure of urbanization). The lower yields from Incline Creek are in part due to the fact that the basin does not cut through major unconsolidated debris flow and landslide deposits in its upper reaches, as does Third Creek.

Similar spatial variations between watersheds are seen when expressing annual suspended-sediment loads per unit of runoff. Annual loads (in tonnes) are divided by annual runoff (in m^3) for each year of record to express annual yields or concentrations, in g/m^3 (Table 3-8). Within basin comparisons using annual concentration data can show variations in sediment production and sources within basins. This approach can be better than using loads per unit area because of the tendency for yield values expressed in T/km^2 to decrease with distance downstream because of greater opportunities for sediment storage.

A revealing result of the analysis of suspended-sediment loads per unit runoff is that production and delivery of sediment from the northern quadrant streams, on average, is about the same as the wetter, western streams if we neglect the data from Third Creek. This is most certainly due to higher unit-runoff rates from the developed areas in the northern quadrant, resulting in higher yields of sediment. However, subsequent analysis of the temporal trends of suspended-sediment transport will show that because of the natural attenuation of sediment loads following disturbance, as well as installation of erosion-control measures, that annual loads are decreasing faster here than in any other quadrant of the Lake Tahoe Basin.

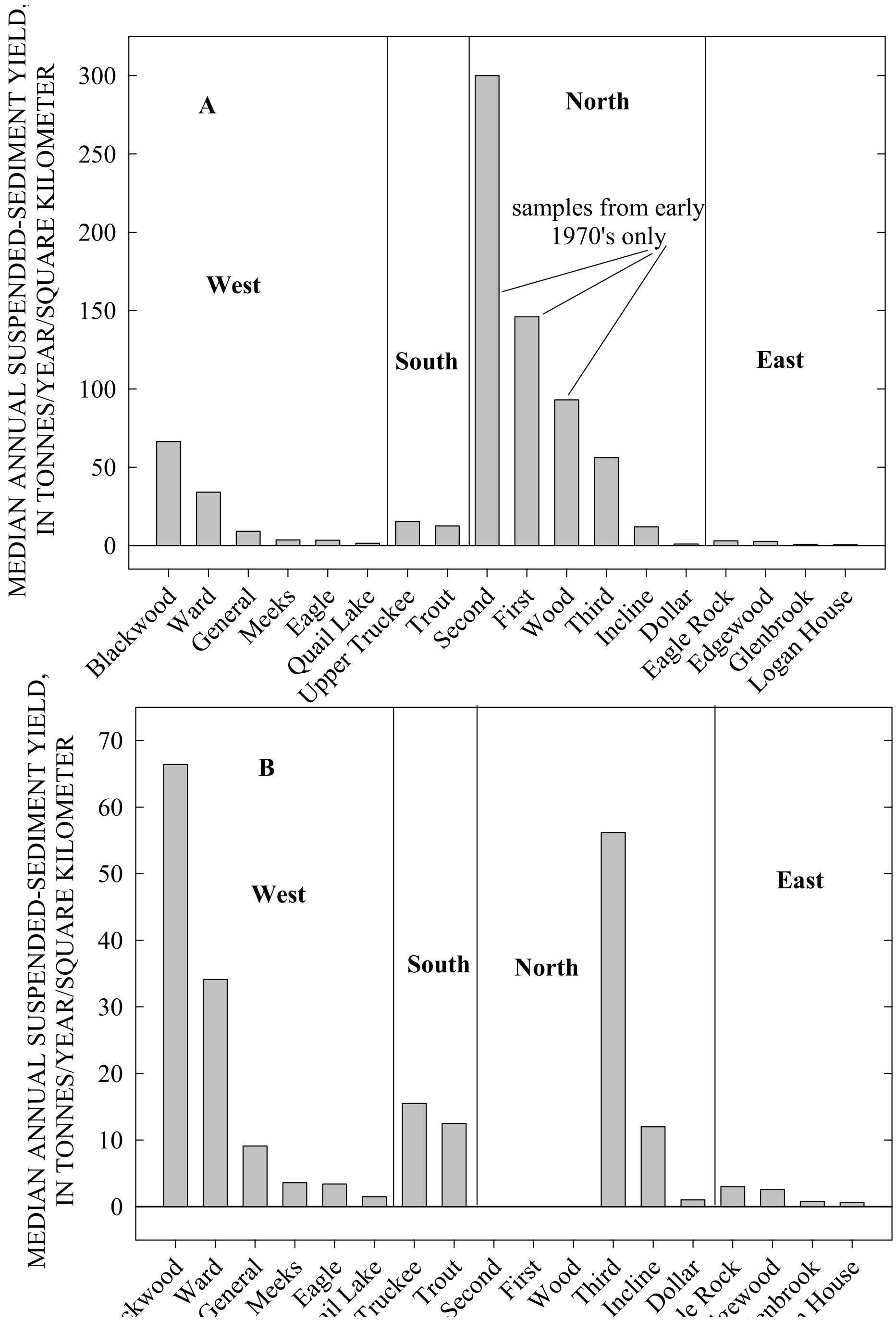


Figure 3-8. Median annual suspended-sediment yields for the 18 index stations (A), and without those northern streams sampled only in the early 1970's (B).

Table 3-8. Annual suspended-sediment loads per unit runoff (annual sediment concentrations). Rows shaded in gray have short periods of record and are not included in calculations of the median values for their respective quadrant.

Stream	Station	Quadrant	Annual sediment concentrations		Percent difference from median
			Median (g/m^3)	Average (g/m^3)	(g/m^3)
Eagle Rock	103367592	E	6.50	7.18	-6.3
Edgewood	10336760	E	6.94	6.98	0.0
Edgewood	10336765	E	7.14	7.14	2.9
Edgewood	103367585	E	12.6	14.6	81.6
Edgewood Trib	10336756	E	3.98	3.98	-42.7
Glenbrook	10336730	E	6.94	7.44	0.0
Logan House	10336740	E	6.16	7.36	-11.2
Median			**6.94**	**7.36**	
First	10336688	N	397	418	1424
Second	10336691	N	964	964	3601
Wood	10336692	N	261	241	902
Incline	10336700	N	29.4	64.4	12.9
Incline	103366993	N	16.7	14.2	-35.9
Incline	103366995	N	22.7	26.4	-12.9
Third	10336698	N	153	181	487
Median			**26.1**	**45.4**	
Grass	10336593	S	14	14	-6.7
Trout	10336770	S	7.8	11.4	-48.0
Trout	10336775	S	10.7	12.1	-28.7
Trout	10336780	S	41.2	41.7	175
Trout	10336790	S	15.0	14.3	0.0
UTR	10336580	S	7.76	8.44	-48.3
UTR	10336610	S	27.1	28.5	80.7
UTR	103366092	S	15.4	14.2	2.7
Median			**15.0**	**14.2**	
Blackwood	10336660	W	54.6	74.2	225
General	10336645	W	11.3	15.0	-32.7
Ward	10336670	W	83.4	81.5	396
Ward	10336674	W	16.8	17.55	0.0
Ward	10336675	W	15.5	18.2	-7.7
Ward	10336676	W	30.7	56	82.7
Median			**16.8**	**18.2**	

3.6 Fine-Grained Suspended-Sediment Loads and Yields

In terms of lake clarity, the delivery of sands and gravels to Lake Tahoe is not a critical issue. Material finer than 0.062 mm, defined as silts and clays, have the ability to remain in suspension for longer periods of time and have a direct effect on lake clarity. Using calculated suspended-sediment loads in combination with relations derived herein between discharge and percent silt plus clay, fine-sediment loads and yields are calculated by multiplying the load for a given day by the percent of material finer than 0.062 mm. Examples of these relations are shown in Figure 3-9.

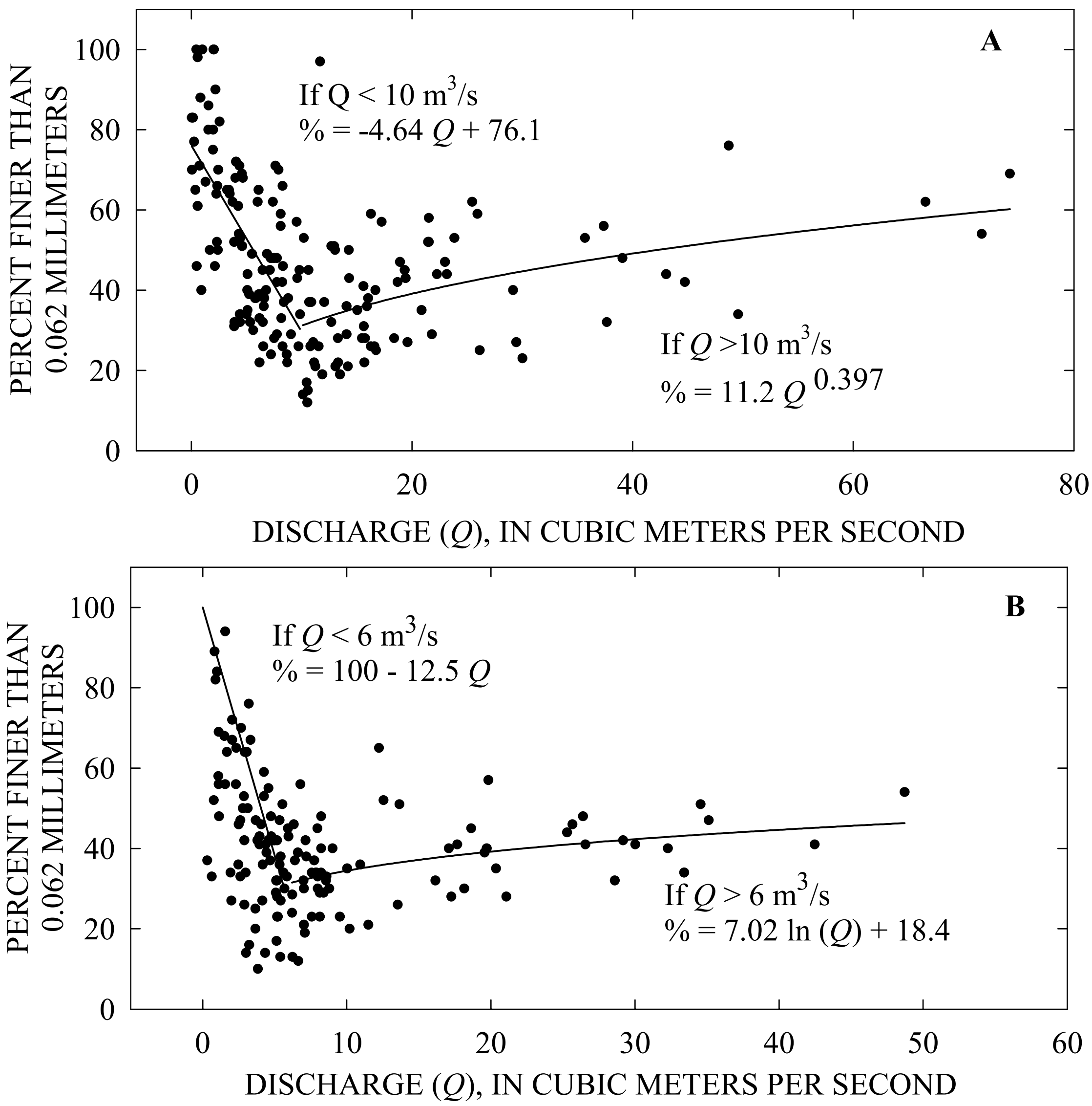


Figure 3-9. Example relations between discharge and percent of suspended load finer than 0.062 millimeters for index stations on the Upper Truckee River, 10336610 (A), and Blackwood Creek, 10336660 (B).

The largest contributors of fine sediment to Lake Tahoe on an annual basis are the Upper Truckee River and Blackwood Creek with median annual values of 1010 T/y and 846 T/y, respectively (Table 3-9). These values are about twice that of the next largest annual contributors Trout (462 T/y) and Ward Creeks (412 T/y). In comparison General Creek, delivers about 53 T/y. The greatest contributor from the eastern side of the lake is the index station on Edgewood Creek (11.4 T/y). Table 3-9 also provides an estimate of the relative contributions of fine load

Table 3-9. Summary of annual fine-grained suspended-sediment loads to Lake Tahoe calculated from measured data. Stations highlighted in green are index stations.

Stream	Station number	Annual Fine Load		Median relative contribution (percent)	Years of data	Drainage Area (km²)
		Average (tonnes)	Median (tonnes)			
UTR	10336610	1261	1010	44	24	142
Blackwood	10336660	1347	846	45	40	29.0
Trout	10336780	624	462	38	40	95.1
Ward	10336676	658	412	47	28	25.1
Third	10336698	462	318	31	26	15.7
Ward	10336670	194	193	30	3	5.2
Trout	10336790	134	141	40	5	105
Incline	10336700	320	129	67	17	18.1
Incline	103366995	74.4	66.7	47	11	11.6
General	10336645	69.2	53.3	29	20	19.3
Grass	10336593	40.4	40.4	31	2	16.6
Incline	103366993	24.4	27.7	36	10	7.2
Eagle[1]	10336630		21.8		3	20.4
Meeks[1]	10336640		19.1		3	22.2
Edgewood	103367585	12.9	11.4	59	11	8.1
Edgewood	10336765	8.5	8.5	89	2	16.2
Glenbrook	10336730	8.8	7.0	80	16	10.5
Quail Lake[1]	10336650		3.2		3	4.2
Dollar [1]	10336684		2.6		3	4.7
Logan House	10336740	3.5	2.3	75	17	5.4

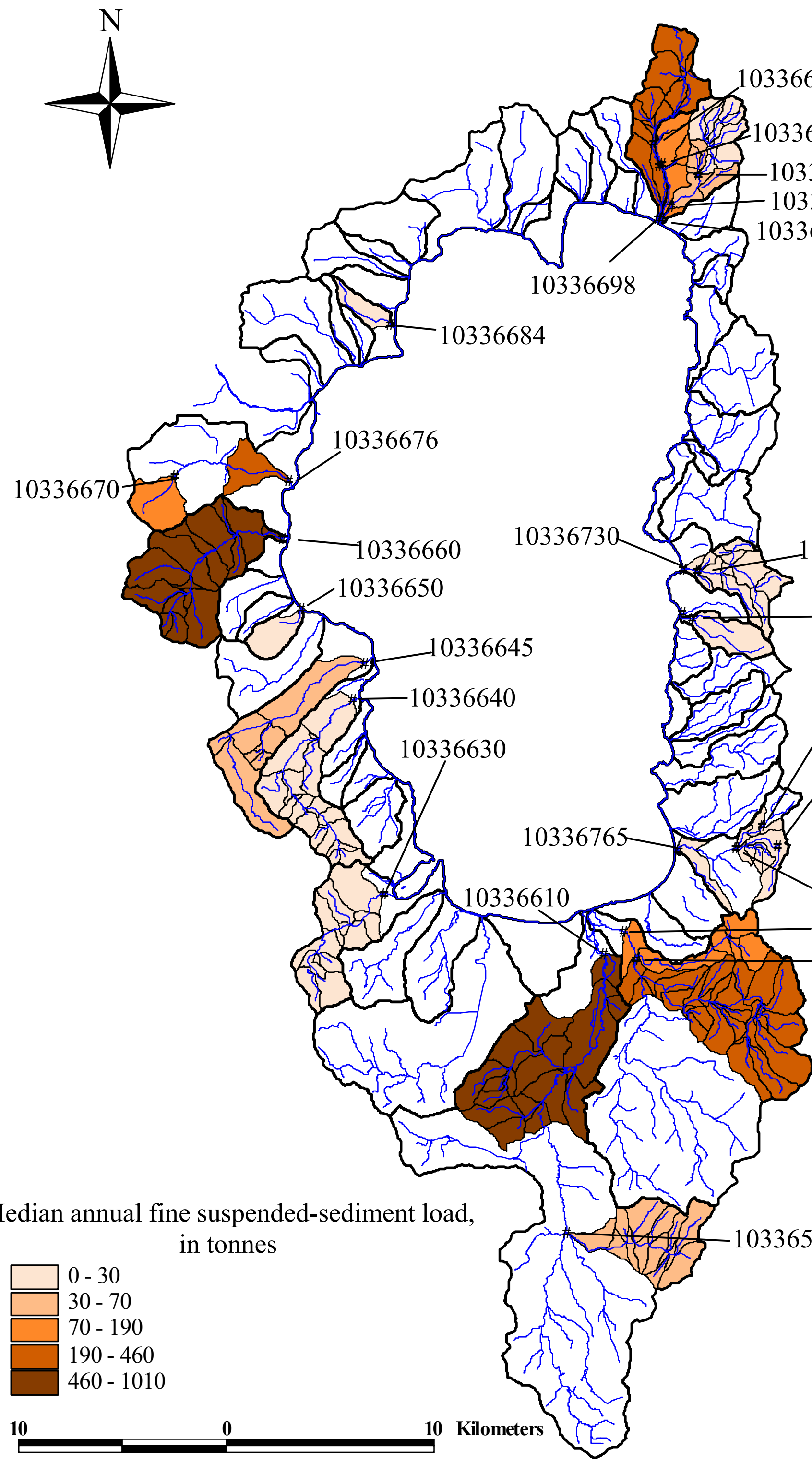
[1] = Data from Kroll (1976).

to total suspended-sediment load on an annual basis. Eastern streams such as Glenbrook, Logan House, and Edgewood Creeks display high percentages of fine loads as does Incline Creek on the north side of the basin, however, these values should be considered as estimates only because of the large degree of scatter in the discharge vs. percent finer relations. The spatial distribution of fine-grained loads is displayed in Figure 3-10.

Table 3-10. Summary of annual fine-grained suspended-sediment yields from Lake Tahoe watersheds. Stations highlighted in green are index stations.

Stream	Station number	Annual Fine Yield		Years of data	Drainage area (km^2)
		Average ($tonnes/km^2$)	Median ($tonnes/km^2$)		
Ward	10336670	37.4	37.1	3	5.2
Blackwood	10336660	45.4	21.5	40	29.0
Third	10336698	29.4	20.2	26	15.7
Ward	10336676	26.2	16.4	28	25.1
UTR	10336610	8.9	7.1	24	142
Incline	10336700	17.7	7.1	17	18.1
Incline	103366995	6.4	5.7	11	11.6
Trout	10336780	6.6	4.9	40	95.1
Incline	103366993	3.4	3.8	10	7.2
General	10336645	3.6	2.8	20	19.3
Grass	10336593	2.4	2.4	2	16.6
Trout	10336790	1.3	1.4	5	105
Edgewood	103367585	1.6	1.4	11	8.1
Eagle[1]	10336630		1.1		20.4
Meeks[1]	10336640		0.9		22.2
Quail Lake[1]	10336650		0.8		4.2
Glenbrook	10336730	0.8	0.7	16	10.5
Dollar [1]	10336684		0.6		4.7
Edgewood	10336765	0.5	0.5	2	16.2
Logan House	10336740	0.6	0.4	17	5.4

[1] = Original data from Kroll,



1976.

Figure 3-10. Spatial distribution of median, annual fine-grained suspended-sediment loads.

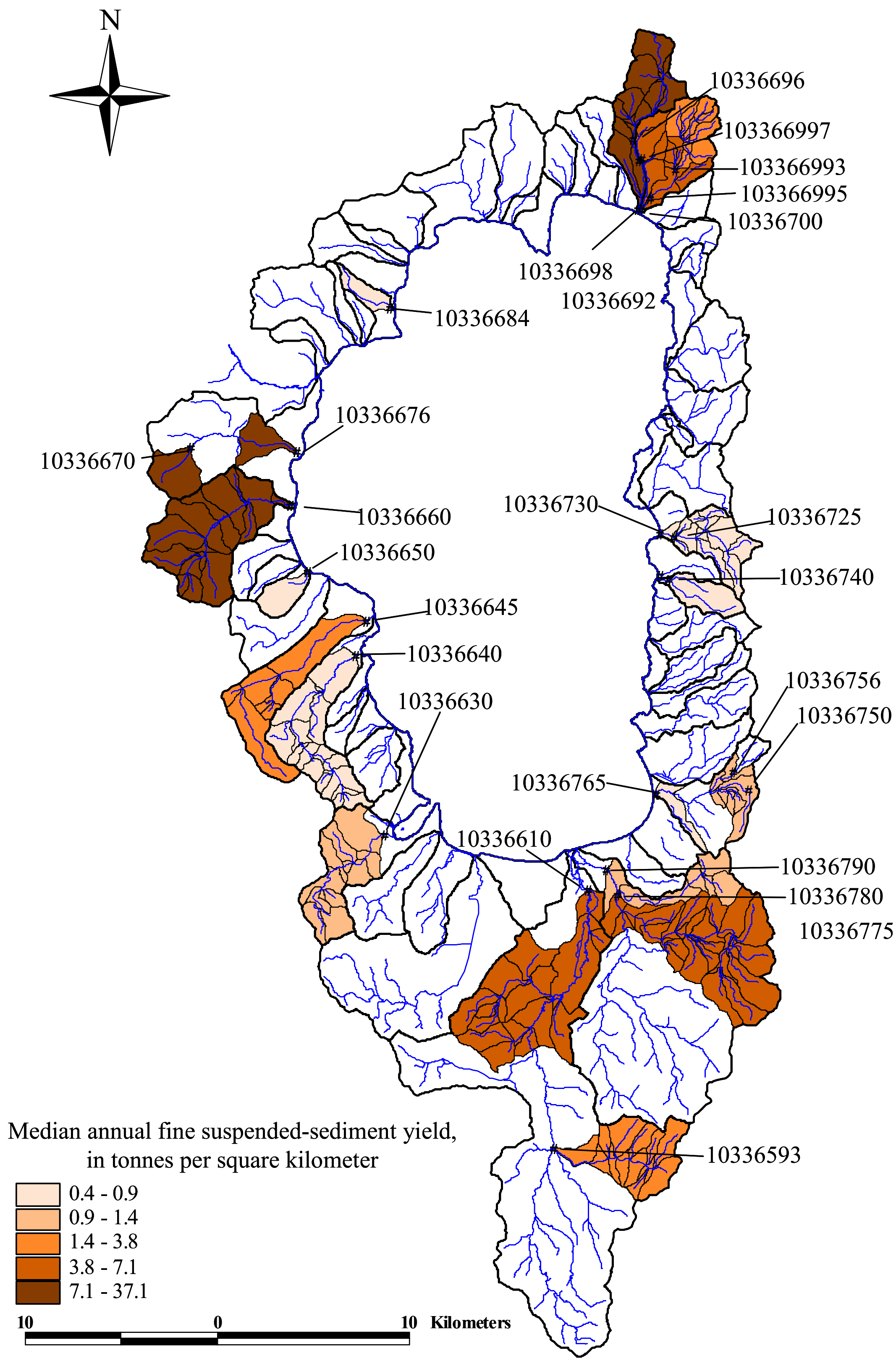


Figure 3-11. Spatial distribution of median, annual yields of fine-grained sediment.

A better understanding of the production and delivery of fine-grained suspended sediment is obtained from expressing transport as load per unit area (yield). Notwithstanding the 37 T/y/km^2 indicated from the headwaters station on Ward Creek (10336670) with only three years of record, it is the index stations representing disturbed streams that produce the most fine-grained sediment (Table 3-10). In descending order, they are: Blackwood (21.5 T/y/km^2), Third (20.2 T/y/km^2), and Ward Creeks (16.4 T/y/km^2). On average, the Upper Truckee River produces about as much fine-grained sediment per unit area as does Incline Creek, about 7 T/y/km^2. The effect of disturbances on fine-grained sediment production is evident by comparing yield values from relatively undisturbed western streams such as General, Meeks, and Eagle Creeks with those from Blackwood and Ward Creeks. On average the disturbed western watersheds produce about 10 times more silt and clay per unit area than the undisturbed basins (Table 3-10; Figure 3-11).

On the eastern side of the lake median, annual fine-grained suspended-sediment yields range from 0.4 T/y/km^2 from the undisturbed Logan House watershed to 1.4 T/y/km^2 in the developed Edgewood Creek watershed, a difference of three and one-half times. Data on yields from the north quadrant are limited to Third and Incline Creeks with Incline producing substantially less silt and clay per unit area than Third. Given the similar degrees of disturbance in these two watersheds, the difference is probably due to more intense erosion processes in the higher elevations of the Third Creek watershed.

3.7 Intra-Basin Variations

Several watersheds including Edgewood, Incline, Trout and Ward Creeks, and the Upper Truckee River contain more than one sampling station and thereby provide a mechanism to compare sediment production from different parts of each watershed (Table 3-11). With the exception of Edgewood and Trout Creeks, median-annual concentrations are greatest at the downstream-most locations of the five watersheds indicating progressively more sediment being entrained from channel sources. Lower yields in the downstream direction along Edgewood and Trout Creeks indicate sediment storage in channels or retention ponds and lakes. Time-series cross sections along Edgewood Creek show average net deposition of about 14 m^3/y/km (1984-2002) along 5.6 km of channels. In addition, sediment retention ponds below the downstream-most station on Edgewood Creek provide additional opportunities to reduce sediment loads before waters enter the lake. Trout Creek contains a small lake between stations 10336780 and 10336790 that traps sediment.

Suspended-sediment loads per unit of runoff increase in the downstream direction along Incline Creek and the Upper Truckee River with sediment entrained from eroding streambanks (Table 3-11). Along the Upper Truckee River this is particularly evident in the sinuous reach adjacent to the golf course where about 650 m^3/y/km of bank materials has been eroded over 2.9 km between 1992 and 2002. That median annual concentrations for the upstream-most stations on Trout Creek and the Upper Truckee River are the same (7.8 g/m^3) is certainly coincidental, yet sediment-transport rates past these two “reference” stations are probably indicative of background rates of sediment production from predominantly forested upland sources in the southern quadrant of the basin.

The exceptionally high median-annual concentration from the upstream-most site on Ward Creek (Table 3-11) agrees with the observations of Reuter and Miller (2000) and Stubblefield (2002) that the badland area in the unvegetated headwaters contributes large quantities of sediment to the main stem where suspended-sediment transport is greatly reduced. However, results for this site (10336670) are based on only three years of record. Suspended-sediment transport increases again in the lower-most reaches with material entrained from eroding streambanks.

Results presented in this section and in Table 3-11 are in general agreement with the narrative on the subject by Reuter and Miller (2000) with the exception of the interpretation about the downstream-most reaches of Ward Creek. Figure 3-11 showing median annual suspended-sediment yields of fine-grained materials is useful in visualizing the trends discussed above.

Table 3-11. Median annual suspended-sediment concentrations for stations along five Lake Tahoe streams. All data expressed in grams of sediment per cubic meter of water (annual concentration). Numbers in parentheses are percent change from next station upstream.

Location	Stream and (Quadrant)				
	Edgewood (E)	**Incline (N)**	**Ward (W)**	**Trout (S)**	**Upper Truckee (S)**
Upstream	6.50	16.7	83.4[1]	7.8	7.8
Mid-basin 1		22.7 (36)	16.8 (-80)	10.7 (37)	15.4 (97)
Mid-basin 2	12.6 (94)		15.5 (-8)	41.2 (285)	
Downstream	6.94 (-45)	29.4 (30)	30.7 (98)	15.0 (-64)	27.1 (76)

[1] = Only three complete years of data.

3.8 Suspended-Sediment Transport from "Reference" and Disturbed Watersheds

Concerns over the role of development and other forms of human-induced disturbances on the delivery of suspended-sediment to Lake Tahoe has been justified on the basis of studies such as those by Glancy (1988) and others documenting the erosion problems associated with these practices. Because of differences in rainfall-runoff characteristics, surficial geology, and land cover, stable, undisturbed watersheds located in the different basin quadrants are likely to have varied sediment-transport regimes.

To differentiate between "background" and "impacted" suspended-sediment loadings from for each of the four basin quadrants, "reference" stations or watersheds are selected. This procedure allows for comparison between relatively undisturbed watersheds and those that have been disturbed or altered by human intervention. Considerations in selecting these reference stations include length of flow and sediment record, amount of channel and watershed disturbance, and comparable drainage areas to the disturbed sites in the quadrant. Reference stations are shown in Table 3-12.

Table 3-12. Reference stations selected for each of the four basin quadrants.

Basin quadrant	Stream	Station number	% Basin with high potential upland erosion[1]	Length of record (years)	Drainage area (km^2)
North	Incline	103366993	3.1	10	7.2
South	Upper Truckee	10336580	18.0	10	36.5
East	Logan House	10336740	0.0	17	5.4
West	General	10336645	1.8	20	19.3

[1] Methods and analysis described in Chapter 6.

Suspended-sediment yields per unit area from disturbed western streams Ward and Blackwood Creeks are 275% to 630% greater respectively, on an annual basis than the “reference” General Creek watershed. These values are comparable to those expressed in terms of yield per unit of runoff (g/m^3; Table 3-8). In the Upper Truckee River watershed, yields per unit area are roughly 75% greater in the flatter alluvial sections where bank erosion is active than at the upstream “reference” station. When compared in terms of median annual concentrations, the disturbed reaches of the Upper Truckee River pass about 250% more sediment per unit of runoff than reaches not experiencing bank erosion. In the eastern quadrant, the index station on Edgewood Creek passes about 330% more suspended-sediment per unit area (about 100% more per unit of water) than does the index station on Logan House Creek.

Comparisons in the north quadrant are difficult given that development in this part of the Lake Tahoe watershed has impacted most of the tributary streams draining the lake. The very high erosion rates from parts of the high elevation areas of Third Creek and comparisons between “reference” and representative, disturbed stations provide additional uncertainty. Still, the upstream-most site on Incline Creek (103366993) is considered a reference because it contains about half the density of unpaved roads compared to the area containing the index stations for Third and Incline Creeks, and few paved roads. Suspended-sediment yields per unit of runoff do show considerable differences with the index sites on Incline (73% greater) and Third Creeks (about 800% greater) that encompass more of the developed area.

3.9 Temporal Trends in Suspended-Sediment Delivery to Lake Tahoe

One of the most critical issues concerning degradation or recovery of Lake Tahoe water clarity is the question as to whether suspended-sediment loads are changing over time, and consequently, are restoration and erosion control efforts effective. Analysis of the temporal variations in sediment delivery to Lake Tahoe are based on the fundamental assumption that precipitation characteristics over the past 40 years have not changed substantially beyond the stochastic variations inherent in runoff production. Because temporal variations in annual suspended-sediment loads are dominated by annual changes in runoff, loads expressed per unit of runoff is a particularly sensitive parameter to interpret temporal trends. Three techniques were used with statistical testing to evaluate temporal trends in the hope of developing parallel lines of evidence. They are:

(1) Annual variations in suspended-sediment loads per unit of runoff;
(2) Daily variations in suspended-sediment loads per unit of runoff; and
(3) Decadal (or less) shifts in the slope and intercept of suspended-sediment transport ratings.

The first two techniques were utilized where there was sufficient mean-daily flow data to calculate annual values for a minimum of five years. The third technique was used where there was no mean-daily flow data but only instantaneous values to develop sediment-transport ratings.

Annual suspended-sediment loads for 21 stations were divided by the total runoff for each year of record and plotted with time to obtain temporal trends of annual concentrations. Examples from ten index stations are shown in Figure 3-12. Statistical analysis of the data shown in Figure 3-12 and for the other 11 stations were conducted to determine the existence of any trends with time. Results of linear regression analysis are displayed in Table 3-13. Only three sites indicating decreasing annual loads have relations significant at the 0.10 level of significance: Upper Truckee River (10336610), Third Creek (10336698), and Trout Creek (10336790). Results for the latter site may be questionable in that there are only 5 years of flow record. In general the results listed in Table 3-13 are not particularly enlightening with extremely low r^2 values, indicating that very little if any of the variation in loads with time is explained. In an attempt to improve statistical significance and provide more reliable results, the analysis was recast using daily values to increase the number of observations (*n*).

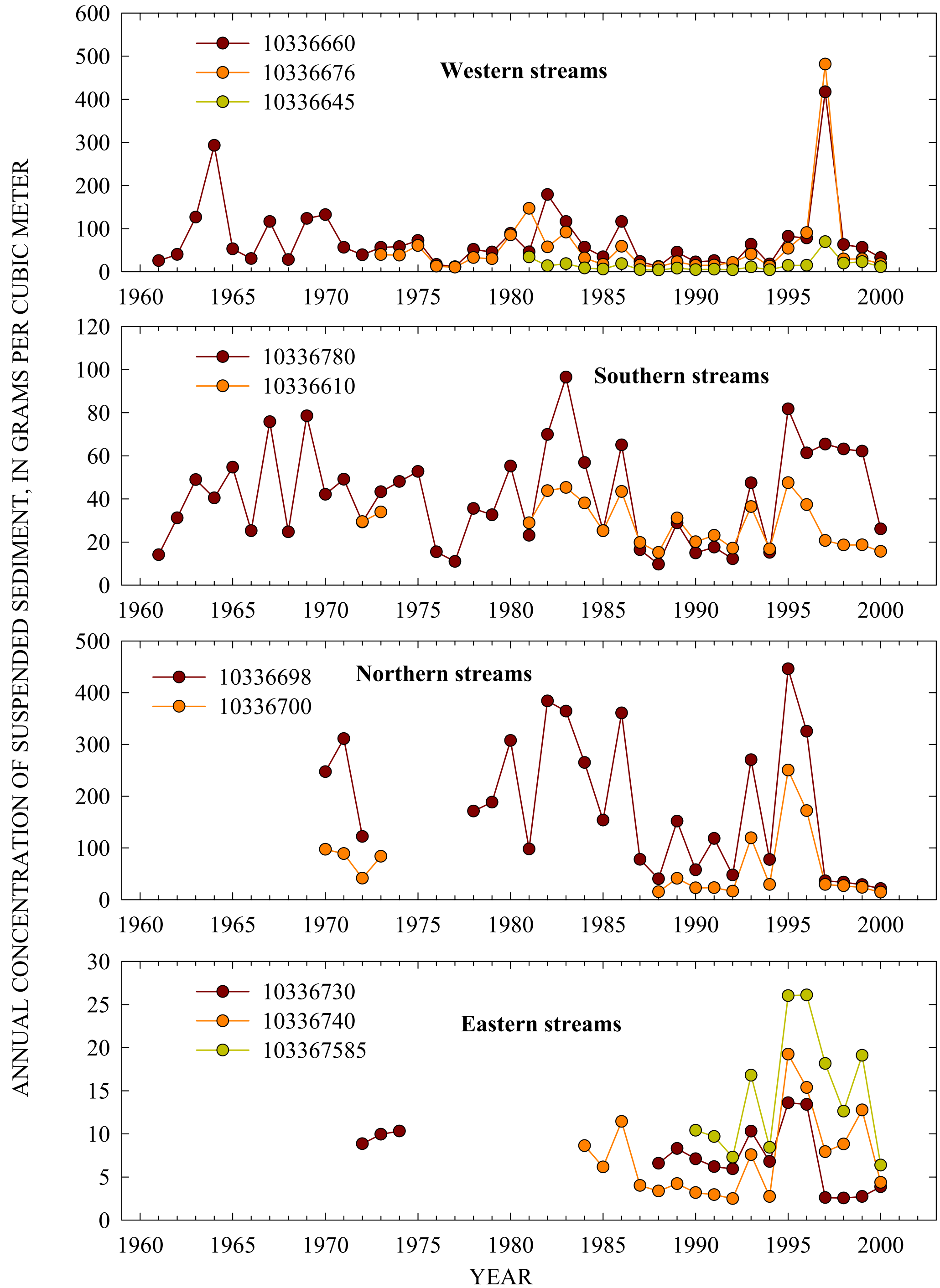


Figure 3-12. Annual concentrations of suspended sediment obtained by dividing annual suspended-sediment load by annual runoff.

Table 3-13. Summary statistics of analysis of temporal trends in annual concentration (in g/m^3).

Stream	Station	Equation	r^2	F-value	P - value	n	Significance and trend
Blackwood	10336660	y=347-0.12x	.0004	0.02	0.90	40	none
General	10336645	y=-907+0.46x	0.03	0.62	0.44	20	none
Ward	10336674	y=92.9-0.04x	.00015	.0009	0.98	8	none
Ward	10336675	y=-1082+0.55x	0.02	0.14	0.72	9	none
Ward	10336676	y=-3733+1.91x	0.03	0.83	0.37	28	none
Trout	10336770	y=298-0.14x	.0018	0.01	0.91	10	none
Trout	10336775	y=-171+0.09x	.0010	0.01	0.93	10	none
Trout	10336780	y=-150+0.10x	.0025	0.10	0.76	40	none
Trout	10336790	y=765-0.38x	0.67	6.21	0.09	5	some (-)
UTR	10336580	y=-330+0.17x	0.01	0.11	0.75	10	none
UTR	10336610	y=1071-0.52x	0.14	3.32	0.08	22	some (-)
UTR	103366092	y=-936+0.48x	0.03	0.26	0.62	10	none
Incline	10336700	y=1055-0.50x	0.01	0.10	0.76	17	none
Incline	103366993	y=-1331+0.67x	0.08	0.72	0.42	10	none
Incline	103366995	y=-3361+1.70x	0.12	1.08	0.33	10	none
Third	10336698	y=10807-5.35x	0.12	3.40	0.08	26	some (-)
Eagle Rock	103367592	y=-727+0.37x	0.18	1.73	0.22	10	none
Edgewood	10336760	y=189-0.09x	0.01	0.06	0.81	8	none
Edgewood	103367585	y=-962+0.49x	0.05	0.50	0.50	11	none
Glenbrook	10336730	y=317-0.16x	0.16	2.74	0.12	16	none
Logan House	10336740	y=-544+0.28x	0.08	1.33	0.27	17	none

Results using daily values show all but five sites with statistically significant trends of decreasing daily concentrations (based on the P-value of the regression) but the results are still considered suspect because of the exceedingly flat slopes indicated by the regression equation (Table 3-14). Although P-values suggest that the slope of the majority of regressions is significantly different than zero (flat, with no trend) this can be largely attributed to the very large sample size. Note the very low slopes of the regressions listed in Table 3-14. Restated, if any trend with time existed, it would show up in the analysis of daily values. That five sites still showed no statistically significant trend is important. These five locations all represent upstream and, or reference sites in the watershed and would, therefore, not be expected to display attenuation of sediment- transport rates in response to disturbance.

Table 3-14. Summary statistics of analysis of temporal trends in mean-daily concentrations (in g/m^3). Stations highlighted in pale yellow signify no discernable trend.

Stream	Station	Equation	r^2	F - value	P - value	n	Significance and trend
Blackwood	10336660	y=18.5-1.74e-4x	.0003	4.75	0.03	14975	definite (-)
General	10336645	y=4.33+7.43e-5x	.0003	2.39	0.12	7756	none
Ward	10336674	y=6.76-7.83e-4x	.006	20.5	0.0001	3652	definite (-)
Ward	10336675	y=6.45-3.47e-4x	.001	4.55	0.03	3653	definite (-)
Ward	10336676	y=14.0-3.84e-4x	.0009	9.41	0.0022	10592	definite (-)
Trout	10336770	y=5.54-2.42e-4x	.001	5.71	0.02	4150	definite (-)

Trout	10336775	y=619-8.87e-5x	.0002	0.94	0.33	4140	none
Trout	10336780	y=25.0+1.51e-4x	.0007	11.0	0.0009	14975	definite (+)
Trout	10336790	y=15.1-3.35e-3x	0.15	465	0.0001	2557	definite (-)
UTR	10336580	y=2.86-7.05e-5x	.004	1.77	0.18	4160	none
UTR	10336610	y=19.4-8.00e-4x	0.03	299	0.0001	9526	definite (-)
UTR	103366092	y=4.20-2.21e-4x	.001	5.55	0.02	4140	definite (-)
Incline	10336700	y=51.7-3.44e-3x	0.01	90.5	0.0001	6839	definite (-)
Incline	103366993	y=8.04-2.93e-4x	.002	6.96	0.01	4171	definite (-)
Incline	103366995	y=18.0-1.08e-3x	.009	37.3	0.0001	4295	definite (-)
Third	10336698	y=128-7.75e-3x	0.04	376	0.0001	10469	definite (-)
Eagle Rock	103367592	y=5.23+7.96e-4x	0.11	469	0.0001	3970	definite (+)
Edgewood	10336760	y=5.34-3.61e-5x	.00002	0.49	0.49	3287	none
Edgewood	103367585	y=10.2-2.54e-4x	.001	5.96	0.01	4383	definite (-)
Glenbrook	10336730	y=8.07-5.27e-4x	0.11	769	.0001	6529	definite (-)
Logan House	10336740	y=4.28+1.75e-6x	5.70E-07	0.004	0.95	6575	none

By using a combination of statistical measures from Table 3-14, we can perhaps extract additional useful information from the analysis. Arbitrarily setting stricter limits on the Type III sum of squares measure (P-value) to 0.0001 and the ratio of explained to unexplained variance (F-value) to near 100, we can discriminate the following five sites as having significant temporal trends of sediment-transport rates:

(1) Upper Truckee River, 10336610 (decreasing);
(2) Incline Creek, 10336700 (decreasing);
(3) Third Creek, 10336698 (decreasing);
(4) Glenbrook Creek, 10336730 (decreasing); and
(5) Eagle Rock Creek, 103367592 (increasing).

The watersheds draining all of these stations have experienced some level of disturbance over the past 40 years and the data indicate that the first four are recovering due to a combination of natural adjustment processes and erosion-control measures. The same cannot be stated conclusively for Ward and Blackwood Creeks where sediment-transport rates remain high. There is no statistical evidence from either the annual or daily analyses that index stations from the three main western streams (Blackwood, Ward, and General Creeks) have increasing rates of sediment transport as reported by Rowe *et al*. (2002). However, negative slopes of the regression equations (indicating the rate of decreasing sediment transport) are greatest for Incline and Third Creeks reflecting more rapid attenuation of transport rates.

3.9.1 Temporal Trends in Fine-Grained Loadings

Statistical analysis identical to that performed for total annual and total mean-daily suspended-sediment loads were carried out for the available fine-loads data. As expected, the analysis of temporal trends in annual, median concentrations of fine-grained suspended sediment mirrors that of total, annual with the Upper Truckee River and Third and Glenbrook Creeks displaying a significant decreasing trend of concentrations (Table 3-15). Aside from the downstream-most station on Trout Creek (10336790) which represents a short period of record, and therefore, a questionable trend, the remaining sites show no discernable trend in annual concentrations. Although two of the western streams (Ward and General Creeks) have positive regression slopes, neither of these relations are significant.

Table 3-15. Summary of statistical analysis of temporal trends in fine-grained median, annual concentrations of suspended sediment (in g/m³).

Stream	Station	Equation	r^2	F-value	P – value	n	Significance
Blackwood	10336660	y=105-0.04x	.0001	0.005	0.94	40	none
Ward	10336676	y=-770+0.40x	0.02	0.48	0.50	28	none
General	10336645	y=-164+0.09x	0.05	0.87	0.36	20	none
UTR	10336610	y=443-0.22x	0.22	5.53	0.03	22	definite (-)
Trout	10336790	y=-50.3+0.03x	0.71	7.43	0.07	5	some (+)
Trout	10336780	y=-22.3+0.02x	0.001	0.05	0.81	40	none
Third	10336698	y=3206-1.59x	0.24	7.58	0.01	26	definite (-)
Incline	10336700	y=1508-0.74x	0.07	1.04	0.33	17	none
Incline	103366995	y=280-0.13x	.009	0.07	0.79	10	none
Incline	103366993	y=-3553+1.8x	0.09	0.82	0.39	10	none
Edgewood	103367585	y=294-0.14x	0.02	0.20	0.67	11	none
Glenbrook	10336730	y=251-0.12x	0.19	3.23	0.09	16	some (-)
Logan House	10336740	y=-154+0.08x	0.03	0.43	0.52	17	none

If we retain the stricter statistical limits on the Type I sum of squares measure used previously (P-value) to 0.0001 and the ratio of explained to unexplained variance (F-value) to near 100, the following sites as having significant trends of fine-grained suspended-sediment transport rates (Table 3-16):

(1) Upper Truckee River, 10336610 (decreasing);
(2) All of the sites on Incline Creek, (decreasing);
(3) Third Creek, 10336698 (decreasing);
(4) Glenbrook Creek, 10336730 (decreasing); and
(5) Edgewood Creek, 103367592 (increasing).

There is again, no indication of increasing sediment-transport rates from the western quadrant streams.

Table 3-16. Summary of statistical analysis of temporal trends in fine-grained daily concentrations of suspended sediment (in g/m³).

Stream	Station	Equation	r^2	F – value	P – value	n	Significance
Blackwood	10336660	y=11.6-1.30e-4x	.001	15.4	.0001	14975	definite (-)
Ward	10336676	y=9.07-3.09e-4x	.006	64.0	.0001	10592	definite (-)
General	10336645	y=3.26-3.24e-5x	.0003	14.6	.0001	7756	definite (-)
UTR	10336610	y=10.4-3.90e-4x	0.05	544	.0001	9526	definite (-)
Trout	10336790	y=6.10+5.69e-5x	.0026	465	.0099	2557	definite (+)
Trout	10336780	y=11.0+3.34e-5x	.0007	7.22	.007	14975	definite (+)
Third	10336698	y=127-7.68e-3x	0.03	369	.0001	10469	definite (-)

Incline	10336700	y=34.0-2.85e-3x	0.04	264	.0001	6839	definite (-)
Incline	103366995	y=13.4-1.66e-3x	0.17	893	.0001	4295	definite (-)
Incline	103366993	y=4.69-5.37e-4x	0.08	351	.0001	4171	definite (-)
Edgewood	103367585	y=8.47-8.48e-4x	0.07	346	.0001	4383	definite (-)
Glenbrook	10336730	y=42.3-9.01e-4x	.0003	2.14	0.14	6529	none
Logan House	10336740	y=4.28-8.15e-5x	.0048	30.9	.0001	6575	definite (-)

3.9.2 Shifts in Suspended-Sediment Transport Ratings

The third line of evidence used to interpret temporal trends in sediment delivery to Lake Tahoe is an analysis of shifts in the sediment-transport rating relations. Mean-daily or annual data are not required for this analysis, only a series of statistical tests to determine whether the relation between instantaneous discharge and instantaneous suspended-sediment concentration is changing with time. An example using data from Third Creek is shown in Figure 3-13.

Regression data from at least three periods for northern quadrant streams (Third, Incline, and Wood Creeks) are provided as an example of this technique. Table 3-17 shows both generally decreasing intercepts (load at 1 m^3/s) and exponents (rate of increase of load with increasing discharge) for the three streams. This is indicative of trends towards lower production of suspended-sediment and is supported by Type I and Type III sum of squares (SS) tests shown in Table 3-18. The Type I SS tests whether the slope of the rating is different than 0.0. The Type III SS tests whether the slopes or intercepts of the ratings are significantly different from one another. The decision matrix is shown in Table 3-18 for five stations on four northern streams with the conclusion that these streams are experiencing reductions in sediment loads across the range of discharges (Figures 3-13 and 3-14a). Particular attention is given to the northern quadrant because of published accounts of historically high suspended-sediment loads.

Results for Blackwood Creek (10336660), although statistically significant are extremely subtle in comparison to the northern quadrant (Figure 3-14b). The same can be said for the Upper Truckee River index station (10336610) where suspended-sediment loads over the range of discharges first increased during the 1983-1992 period but then decreased during the 1993-2002 period to values below the 1972-1982 period. Ward Creek, the other large sediment contributor also does not show conclusive evidence that loads are decreasing across the range of flows over the entire period, particularly at high discharges. Results for Blackwood and Ward Creeks, and the Upper Truckee River indicating lower suspended-sediment loads during the period 1993-2002 probably reflect the enormous flushing of stored sediment that took place during the January 1997 event.

Table 3-17. Comparison of suspended-sediment transport ratings for different periods for index stations on three north quadrant streams.

Stream	Period	Intercept	Exponent	n
Third	1965-1974	103	2.84	248
	1975-1984	18.3	2.02	74
	1985-1994	46.7	2.05	235
	1995-2002	6.3	2.10	267

Incline	1965-1974	85.9	2.51	229
	1975-1984	no data	no data	-
	1985-1994	18.4	2.12	224
	1995-2002	5.0	2.09	203
Wood	1969-1970	967	2.76	50
	1991-1996	69.5	1.96	54
	1997-2002	31.2	2.22	40

Table 3-18. Decision matrix using Type I and III sum of squares tests to determine if shifts in suspended-sediment transport ratings are statistically significant for four northern quadrant streams.

Stream	Station	Sum of Squares Test	Testing	F - value	P- value	Result	Conclusion
First	10336688	Type I	slope = 0	141	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	6.55	.0003	Slopes are not equal	Ratings are not = and not parallel
		Type III	Intercepts =	26.8	<.0001	Intercepts are not equal	Ratings shift (mix) First and Last Rating Shift (-)
Wood	10336692	Type I	slope = 0	189	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	5.65	0.0043	Slopes are not equal	Ratings are not = and/or not parallel
		Type III	Intercepts =	36.8	<.0001	Intercepts are not equal	Ratings shift (-)
Third	10336698	Type I	slope = 0	489	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	1.49	0.215	Slopes are equal	Ratings = and/or parallel
		Type III	Intercepts =	185	<.0001	Intercepts are not equal	Ratings shift (mix) First and Last Rating Shift (-)
Incline	10336700	Type I	slope = 0	514	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	4.61	0.0102	Slopes are not equal	Ratings are not = and/or not parallel
		Type III	Intercepts =	260	<.0001	Intercepts are not equal	Ratings shift (-)
Incline	103366995	Type I	slope = 0	298	<.0001	Slopes do not equal 0	Ratings valid
		Type III	slopes =	1.72	.1816	Slopes are equal	Ratings = and/or parallel
		Type III	Intercepts =	53.5	<.0001	Intercepts are not equal	Ratings shift (mix) First and Last Rating Shift (-)

Convincing evidence of reductions in sediment-transport rates is also available from this analysis for the index station on Edgewood Creek (1093367585), showing parallel shifts to lower suspended-sediment loads significant at the 0.0001 level.

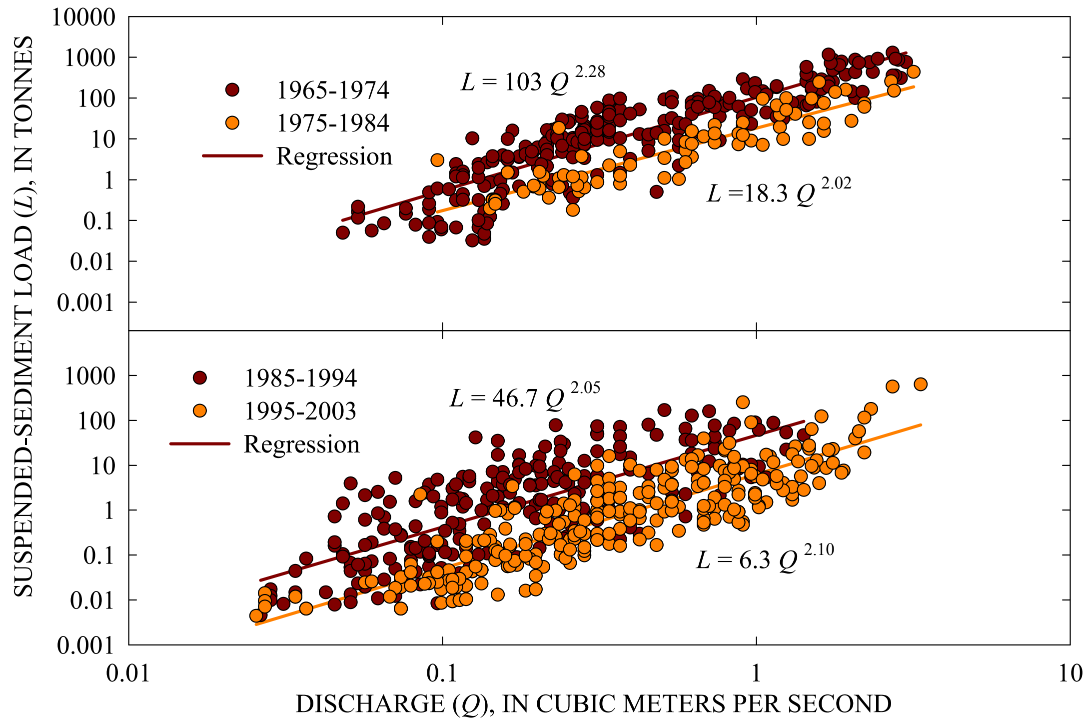
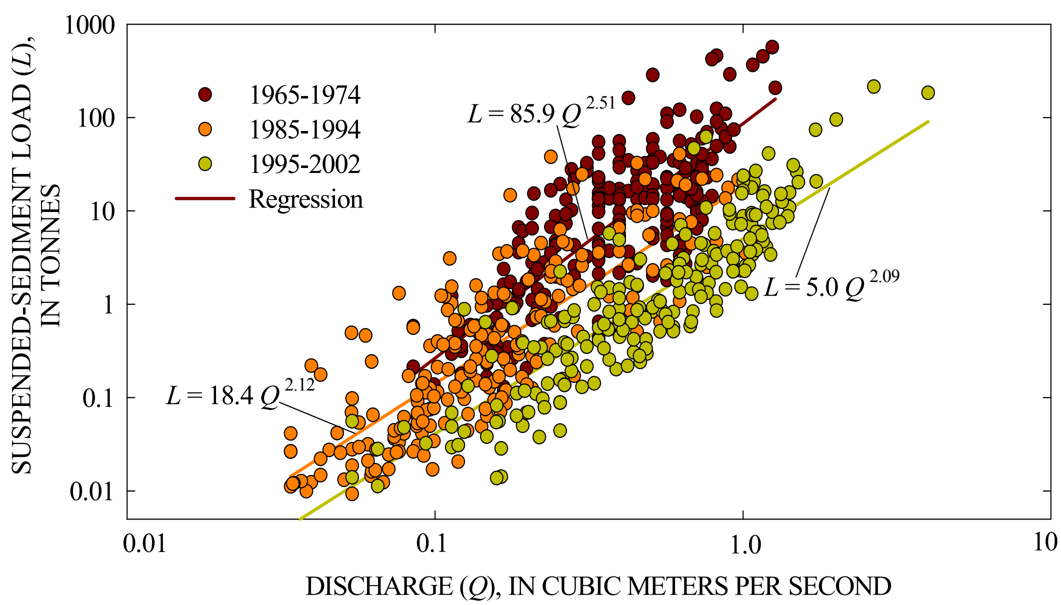


Figure 3-13. Shift in suspended-sediment transport ratings to lower loads at a given discharge across the range of discharges for the index station on Third Creek (10336698).



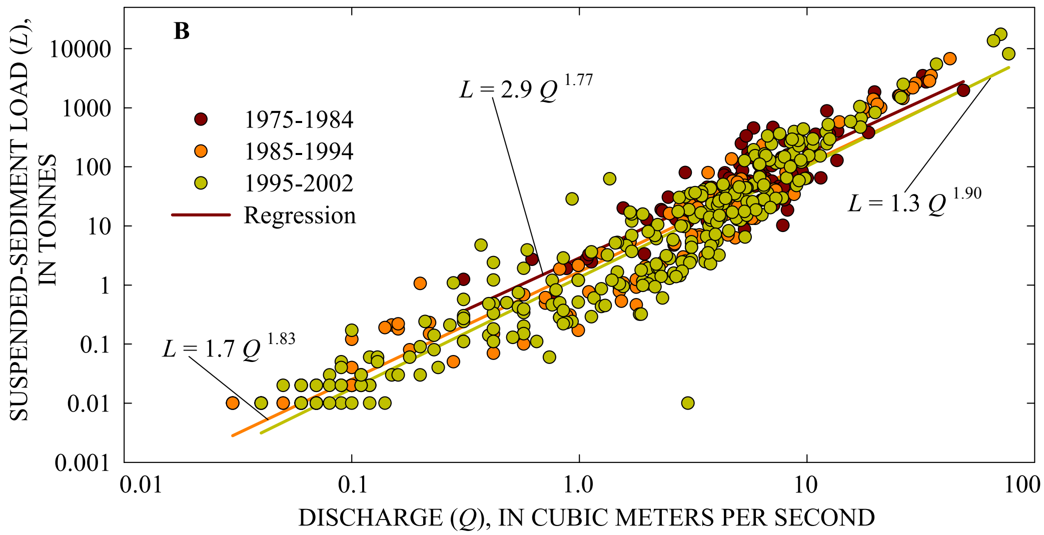


Figure 3-14. Shift in suspended-sediment transport ratings to lower loads at a given discharge across the range of discharges for the index station on Incline Creek (10336670) (A), and no discernable shift for index station on Blackwood Creek (10336660) (B).

3.10 Summary of Temporal Trends Analysis

Parallel lines of evidence have been provided that show significant reduction in sediment production and delivery from index stations draining developed watersheds in the north quadrant of the basin. Streams such as Third, Incline, and Wood Creeks produce much less suspended-sediment today than they did 30 to 40 years ago. In part this is probably due to natural adjustment processes that cause sediment-transport rates to reduce non-linearly with time following disturbance (Simon, 1992). Erosion control measures have probably also played an important role in these documented reductions in suspended-sediment transport rates. Evidence from other large sediment-producing watersheds such as the Upper Truckee River and Blackwood and Ward Creeks is mixed. Data for the Upper Truckee River does indicate that suspended-sediment transport to Lake Tahoe is decreasing based on annual trends of sediment load per unit of runoff (Tables 3-13 to 3-16). Sediment delivery from Blackwood and Ward Creeks has probably not changed significantly over the past 40 years, in contrast to the increases in loads reported by Rowe *et al*. (2002).

3.11 Relations Between Suspended Sediment Loads and Secchi Depth

The degrading clarity of Lake Tahoe's waters has been quantified through measurements of secchi depth (Figure 1.1) that have conclusively shown a reduction over the past 35 years. With fine-grained suspended-sediment transport loads being a primary suspect of this reduction in water clarity, an attempt was made to correlate fine-grained loadings with secchi depth.

Secchi-depth data were supplied from Reuter (2003, U. California at Davis, written commun.) for two locations in Lake Tahoe. The first disk was located near the shoreline, 0.3 km southeast of Tahoe Pines, California (close to the mouth of Ward Creek); the second disk was located mid-lake. Both monthly average and annual average secchi-depth data was provided. The duration of available data are summarized in Table 3-19.

Table 3-19. Duration of secchi-disk data.

Disk location name	Longitude	Latitude	Period of record	Duration (years)
LTP (Lake Tahoe Productivity)	39 05.630 N	120 09.000 W	Jul 1967 – Dec 2002	35.5
MLTP (Mid-Lake Tahoe Productivity)	39 09.220 N	120 02.120 W	Jul 1969 – Dec 2002	33.5

After initial data analysis with data from both disks, only the nearshore gage was used for correlation analysis. Regression analyses were carried out between both the actual secchi depth in meters, and the change in secchi depth from the previous record (as an overall decreasing trend in secchi depth was evident over the period of record), for various combinations of suspended-sediment load parameters:

(1) Annual and monthly data;
(2) Total load and fine load; and
(3) Loads for Ward Creek and the sum of loads for Ward Creek, Upper Truckee River and Blackwood Creek.

These streams were selected for inclusion in the analysis because they represent some of the largest sediment contributors to the lake (particularly fine-grained sediments) and with the exception of the Upper Truckee River, are in general proximity to the nearshore secchi disk.

Relations between annual load and secchi depth, and all monthly load and secchi depth did not exhibit strong correlations. However, when the suspended-sediment load data from the spring melt period were isolated, several of the relations with secchi depth were shown to be statistically significant at the 0.05 level.

3.11.1 Suspended-Sediment Loads During May and June

Non-organic material (suspended sediment, as opposed to algae) made up a greater proportion of suspended matter during the spring-melt months of April to July, particularly May and June when snowmelt is greatest (J. Reuter, 2003, U. California at Davis, per. commun.). Additional regression analyses were conducted, therefore, between secchi depth and total monthly loads for these months. Examination of the mean-monthly discharge statistics for major sediment-producing index stations indicated flows consistently peaked in the months of May and June for all gaging stations analyzed (Table 3-20). These months were, therefore, used for spring analysis.

Table 3-20. Average peak flows for May and June.

Stream	Station	Mean Discharge	
		May (m^3/s)	June (m^3/s)
Upper Truckee	10336610	8.69	7.30
Blackwood	10336660	3.62	2.86
Ward	10336676	2.60	2.12
Third	10336698	0.56	0.66
Trout	10336780	2.22	2.62
Incline	10336700	0.48	0.44

Although none of the r^2 values were extremely promising, the relation between secchi depth, or change in secchi depth produced several statistically significant relations (Table 3-21). Regression statistics were generally stronger for the change in secchi depth rather than the absolute magnitude of the depth. The number of pairs of data was 25 (degrees of freedom: 24). Using a 95% confidence level (single class), the critical F-value is 4.26. As the calculated F-value is greater than this in all eight cases, all correlations are shown to be statistically significant. Example relations are plotted in Figure 3-15.

Table 3-21. Summary statistics for relations between two secchi-depth parameters and several sediment-load parameters using the sum of loads during May and June.

Parameter	Secchi depth			Change in secchi depth		
	r^2	F-value	p-value	r^2	F-value	p-value
Sum (Ward, Blackwood, UTR): Total Load	0.249	7.63	0.011	0.412	16.1	<0.001
Ward Creek: Total Load	0.185	5.24	0.032	0.340	11.8	0.002
Sum (Ward, Blackwood, UTR): Fine Load	0.236	7.43	0.012	0.408	16.5	<0.001
Ward Creek: Fine Load	0.266	8.71	0.007	0.390	15.4	<0.001

Table 3-22. Summary statistics for relations between two secchi-depth parameters and several sediment-load parameters using June data only.

Parameter	Secchi depth			Change in secchi depth		
	r^2	F-value	p-value	r^2	F-value	p-value
Sum (Ward, Blackwood, UTR): Total Load	0.424	16.9	<0.001	0.461	19.6	<0.001
Ward Creek: Total Load	0.357	15.0	<0.001	0.389	17.2	<0.001
Sum (Ward, Blackwood, UTR): Fine Load	0.365	15.5	<0.001	0.391	17.3	<0.001
Ward Creek: Fine Load	0.395	15.6	<0.001	0.507	24.7	<0.001

Regression statistics using the June-load regressions tend to be consistently higher than those using loads for May plus June load (Table 3.22). Perhaps this related to the observation that even though peak loads generally occur in May, it may take some time for the fine-grained sediments to make their way out into the lake, thereby affecting the disks offshore. Again using 95% confidence level (single class), for 24 degrees of freedom, the critical F-value is 4.26. With the calculated F-values for each June regression being greater than the critical value, in all eight cases there is no reason to reject that hypothesis that there is a significant relation between the pairs of variables shown in Table 3-22. Two examples of this are shown in Figure 3-16. It is also interesting to note that relations for fine sediment emanating from Ward Creek have among the strongest statistical significance of all those attempted owing to the creek's proximity to the nearshore disk.

3.11.2 Discussion

It appears that low and moderate flows do not have a strong influence on secchi depth/change in secchi depth, as there is consistently considerable scatter in values for these variables when suspended loads are low. However, large snowmelt discharges causing large suspended-sediment loads, subsequently have been observed to cause notable declines in secchi depth. Because of the great inherent complexities in delivery and mixing processes that are masked by these simple regression techniques, they are probably conceptually accurate but quantitatively, contain a reasonable degree of uncertainty. Still, the fact that the tested regressions are statistically significant beyond the 0.05 confidence level indicate that:

(1) suspended-sediment loads, particularly those during the spring melt season can be used as an indicator of lake clarity, and
(2) maintenance of the long-term monitoring station at the mouth of Ward Creek (10336676) that includes sampling for suspended-sediment and suspended particle-size distribution is justified as a basis of comparison with secchi depth data (Figures 3-15b and 3-16b).

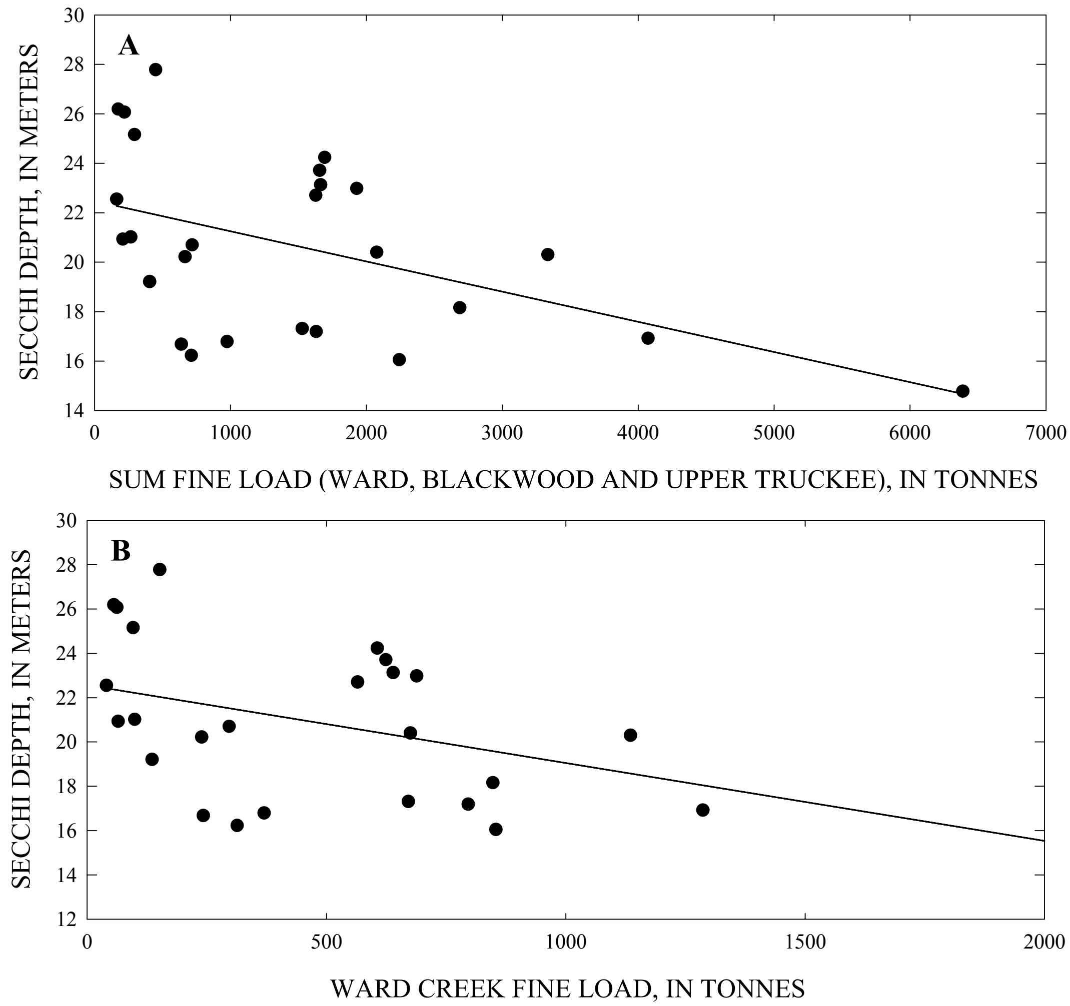


Figure 3-15. Linear regressions between fine suspended-sediment load and secchi depth for May and June using sum of the fine load for Ward Creek, Blackwood Creek and Upper Truckee River (A), and Ward Creek fine load only (B).

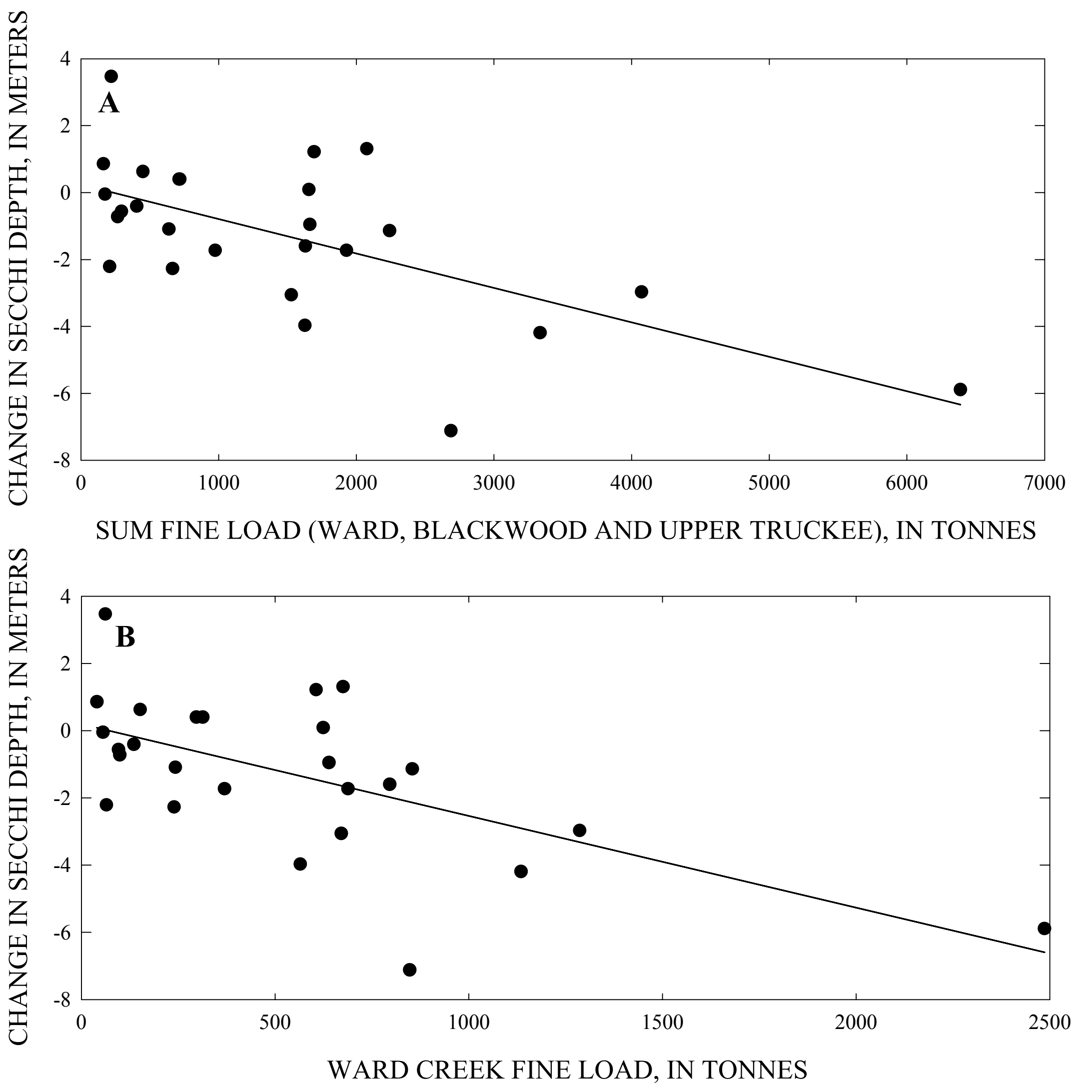


Figure 3-16. Linear regression between fine load and change in secchi depth for May and June using sum of the fine load for Ward Creek, Blackwood Creek and Upper Truckee River (A), and Ward Creek fine load only (B).